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Alouette III helicopter with a CW CO_2-laser system

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Titel : Remote vibration measurements at a Sud Aviation Alouette III helicopter with a CW CO$_2$-laser system

Auteur(s) : Ing. H.E.R. Boetz

Datum : september 1993

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Door de ervaringen van de oorlogen in Vietnam, Korea en de Golf, met relatief veel fratricide, is er een grote belangstelling voor detectie, classificatie en identificatie van doelen en andere objecten. De in dit onderzoek toegepaste non-coöperatieve techniek berust op metingen met een laserbundel (golflengte 10 µm), waarmee trillingen op afstand gedetecteerd kunnen worden op een precies aan te wijzen plaats in het gezichtsveld van een passieve sensor. Laserdetectie kan gezien worden als een alternatief voor akoestische detectie van trillingen, met als voordeel de precieze aanwijzing en de afwezigheid van storende invloeden van omgevingsgeluid, bijvoorbeeld geschut. De techniek wordt ook voor grondvoertuigen van belang geacht. De laser maakt selectieve aanwijzing van de doelen mogelijk, waardoor storende invloeden van andere voertuigen en van de omgeving vermeden kunnen worden.

Het doel van het in dit rapport beschreven onderzoek is het aantonen van de mogelijkheid op enkele kilometers afstand trillingen van helicopters waar te nemen en te onderzoeken of de karakteristieke frequenties daarvan gevonden kunnen worden.

De metingen zijn verricht aan een Alouette III helicopter, ter beschikking gesteld door de KLu. De helicopter werd aangestraald met een laagvermogen CO$_2$-laserbundel. De door het Doppler effect gemoduleerde ontvangen straling werd na optische detectie via een FM-ontvanger omgezet naar een audiofrequent signaal, waaraan frequentie-analyse plaatsvond. De metingen zijn verricht tot op 4 km afstand.

De resultaten tonen aan dat het mogelijk is op enkele kilometers afstand de karakteristieke trillingen te bepalen, waardoor de mogelijkheid tot identificatie is aangetoond. Aanbevolen wordt de ontwikkeling van de laserdetectietechniek voort te zetten, in het bijzonder betreffende de mogelijke toepassingen van deze techniek voor detectie en classificatie van landvoertuigen. Te denken valt aan bepaling van de karakteristieken van de aandrijving (motoren), de verende ophanging en de transmissie. Het onderzoek wordt voortgezet met de uitwerking van metingen die in 1992 te Meppen aan voertuigen en achtergronden werden verricht.

De ontwikkeling van een nieuw lasersysteem, werkend bij een (oogveilige) golflengte van ca. 1.5 µm, wordt als een belangrijke volgende stap beschouwd. De mogelijke operationele en functionele voordelen zijn met name compactheid en betrouwbaarheid. De grotere invloed van de atmosfeer, met name turbulentie, verstrooiing en absorptie, dient nader onderzocht te worden.

Toevoeging van coöperatieve identificatie via een optische transponder is een natuurlijke uitbreiding voor trillingsdetectie op basis van lasers.

ABSTRACT

This report describes an experiment with a helicopter to quantify the performance of our experimental multifunctional CO_2-laser heterodyne detection system[5,7] as a vibration detection instrument. The laser system emitted a beam with a diameter of 35 mm with a divergence of 0.5 mrad and a continuous output of 0.4 Watt.

The purpose of our measurements was to measure the vibration spectra of a helicopter from the Dutch Air Force at distances between 0,5 to 6 km at various aspect angles. Vibration detection with the help of lasers might prove important for classification of targets. Especially helicopters are of interest because of the typical constant rotor speeds and fixed speed-ratio's between the tail- and main rotor (T/R-ratio) and other characteristics of the spectra.

The obtained spectral components are compared with maintenance (rotortuning) frequency measurements done at the airbase with accelerometers. The results are in accordance with each other. The rotor frequencies have been determined at all positions of the helicopter. Depending of the place where the laser beam hits the target, the amplitudes of the spikes in the frequency spectrum may vary significantly. With an Advantest R9211C FFT spectrum analyser a measurement will take at least one second, yielding a fair recognisable spectrum at distances of the helicopter up to 4 km.

SAMENVATTING

Dit rapport beschrijft een experiment met een helicopter om de prestatie te testen van ons experimenteel multifunctioneel CO_2-laser heterodyne-detectie systeem[5,7] als een vibratie detectie instrument. Het lasersysteem zendt een bundel uit met een diameter van 35 mm met een divergentie van 0,5 mrad en een continu vermogen van 0,4 Watt.

Het doel van onze metingen was het meten van vibratiespectra van een helicopter op afstanden van 0,5 - 6 km onder verschillende hoeken. Vibratiemetingen m.b.v. een laser zouden belangrijk kunnen worden voor classificatie van doelen. In het bijzonder zijn helicopters interessant vanwege de konstante rotorsnelheden en de vaste snelheidsverhouding van de staart- en hoofdrotor (T/R-ratio), evenals andere karakteristieke pieken in de spectra.

De gemeten trillingen bij de Alouette III helicopter liggen hoofdzakelijk in het frequentiegebied 5-1100 Hz, met de grootste pieken in het 5-600 Hz gebied. De door ons gemeten frequentiecomponenten zijn vergeleken met onderhouds (rotortuning) frequentiemetingen die zijn gedaan op de vliegbasis m.b.v. versnellingsopnemers aan de helicopter. De resultaten komen met elkaar overeen. De rotorfrequenties zijn in alle posities bepaald . Afhankelijk van de plaats waar de laserbundel het doel treft, kunnen de in de spectra voorkomende frequentiepieken belangrijk in amplitude verschillen.

Met een Advantest R9211C FFT-analyser duurt een meting ten minste 1 seconde ter verkrijging van een herkenbaar spectrum, tot afstanden van 4 km tot de helicopter.

CONTENTS

1   INTRODUCTION

These vibration measurements took place at five distances: 0.5 km (position A), 0.9 km (B), 2,4 km (C), 4 km (D) and 6 km (E). At each position the helicopter was hovering for a while at flight levels of respectively 300, 600, 1000, 1500 and 2000 ft and at four aspect angles with respect to the front side of the helicopter and us: 0° (front), 45°(left), 90°(left) and 180°.(tail). Photographs below depicts three of the four used aspect angles of the helicopter.

Photo 1:   Helicopter viewed at 0°

Photo 2:   Helicopter viewed at 45°

Photo 3:   Helicopter viewed at 180°

2 MEASUREMENT SET-UP

2.1 Equipment used

- TNO-FEL Multifunctional Heterodyne CO_2-laser set-up with the multi-mode RF transceiver unit switched to the transmit CW mode.

  Beam Diameter: 35 mm

  Beam Divergence: 0.5 mrad.

  System Output: about 0.4 Watt

  Polarisation: Linear $\pm 5°$ Vert.

  Liquid nitrogen cooled HgTeCd detector from Societe Anonyme de Telecommunication (SAT, France), class C1A with 4541016 Dewar flask.

  Lock-in stabilizer from Lansing Research Corporation (USA), model 80.215.

- Rhode & Schwarz ESVP test receiver in FM mode, AFC ON, tuned at 140 MHz (the carrier frequency of our laser heterodyne signal).

- Nakamichi CR-1 Audio cassette deck, using Maxell XL II music-cassettes. Settings: Dolby C, SX II, 70 µsec, MPX filter switched off.

- Advantest R9211C FFT servo spectrum analyser with built-in printer unit.

- Advantest R3361A RF spectrum analyser.

2.2   The laser system
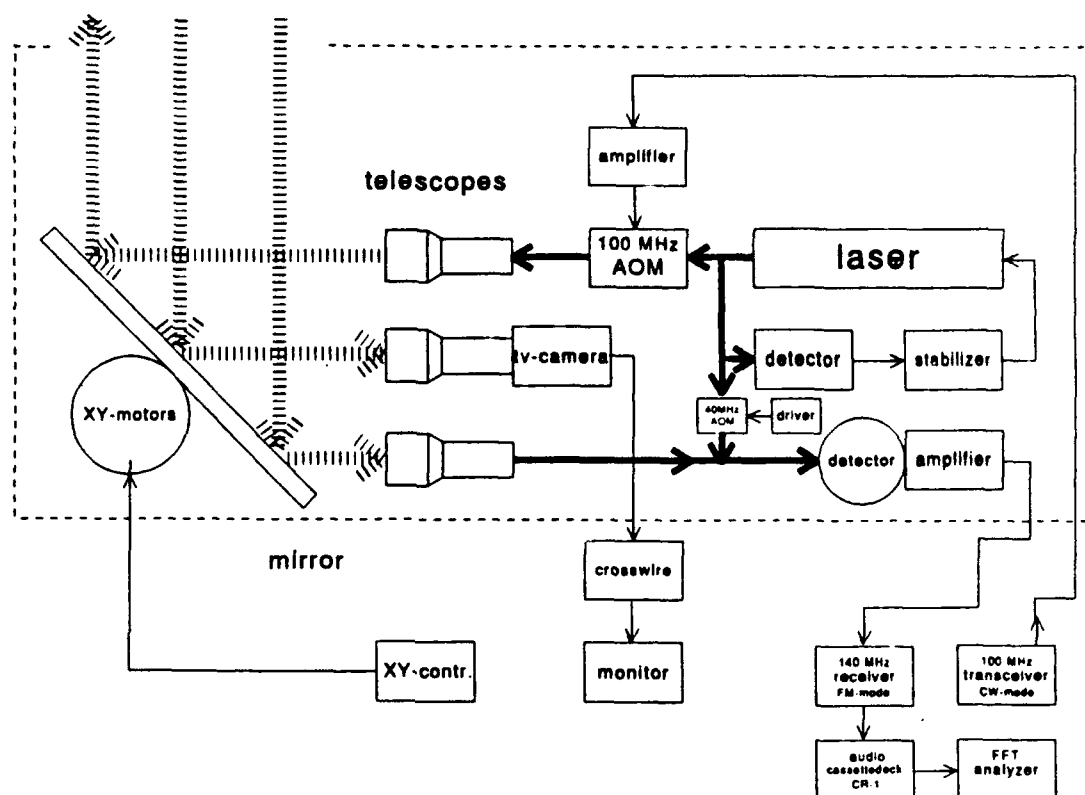
Figure 1:   Multi-functional heterodyne CO_2-laser system

The laser is a water cooled, RF exited at 80 MHz, CO_2-waveguide laser model WL8 from Edinburgh Instruments Ltd. with a output power of approximately 4 Watt. The output telescope blows up the beam diameter with a factor 15 in order to get a reduction of the divergence of the laser beam by the same amount to 0.5 mrad.

The 10.6 µm laser beam of 0.4 W is invisible for the most common military night vision viewing devices (non-thermal imaging) and is absolute eye safe.

The laser is stabilized with a lock-in stabilizer model 80.215 from Lansing Research Corporation (USA).

The infrared receiving device is a liquid nitrogen cooled C1A HgCdTe detector with a 4541016 Dewar flask, from Societe Anonyme de Telecommunications (SAT) (France). For this detector, I designed an impedance matched RF (130-150 MHz) low noise (Nf=1dB) & lf amplifier block.

This block is directly mounted at the detector, in order to reduce electrical interference to a minimum. The lf part is intended for optical adjustment & test purposes of the set-up.

The scan mirror has a size of 20 * 20 * 1 cm and is controllable by means of two stepper motor's, a trackball/ joy-stick/ or a computer.

With the help of a b/w-video camera with a telescope and an electronic crosswire we can aim the beam very accurate at a target.

The laser system is originally designed as a multifunctional system[5] suitable for a number of modulation techniques.

For this reason a 100 MHz acoustic optic modulator (AOM) with a RF bandwidth of 20 MHz is used in order to be able to modulate the laser beam output with any kind of signal. The modulation modes available are:

- AM (beam on/of); a digital pseudo noise code with auto-correlation technique for computerized pulse compression. Application: ranging.

- Pulsed FM (chirp) and RF pulse compression is used. Application: range and velocity measurements.

Both pulse compression techniques improve the signal-to-noise-ratio of the received signal significantly, compared to a single on/off-pulse with the same power instead. Both pulse compression techniques are spread spectrum techniques.

However, for vibration measurements, only a continuous carrier (i.e. an CW laser beam) and a FM receiver at the output of the IR detector pre-amplifier are needed.

Our system has *two* Acoustic Optic Modulators. The second AOM is placed in the receiver LO-path and shifts the LO-beam by 40 MHz. This set-up was recently chosen in order to suppress mainly optical and some minor electrical leakage effects as well and is described in a report[2].

In figure 1, right below, is depicted a 100/140 MHz transceiver of which the transmit part is switched to the CW mode for vibration measurements. This transceiver was originally designed by me for AM and FM-pulse compression, not for FM demodulation. So, a test receiver ESVP from Rhode & Schwarz is used instead with on-board: FM mode, automatic frequency control (AFC) and an adjustable IF (intermediate frequency) bandwidth.

3 SOME THEORY

3.1 Heterodyne principle

Two sinusoidal signals with circular frequencies ω_1 and ω_2 mixed in a non-linear device produce a signal containing a product of the signals. The result contains signals at the sum and the difference frequencies, hence contains an upper-sideband (USB) and a lower-sideband (LSB).

In our set-up, the optical source is a continuous wave CO_2-laser emitting a coherent linear polarized beam with a circular frequency ω_{opt}.

Radiation detection takes place with a IR detector, which has a quadratic behaviour: the detector current is proportional with the incident radiation intensity, so with the square of the total field strength.

Signal ω_s ·········> ·········> $\omega_s + \omega_{lo}$ | HgCdTe-IR-det.

RF
low noise
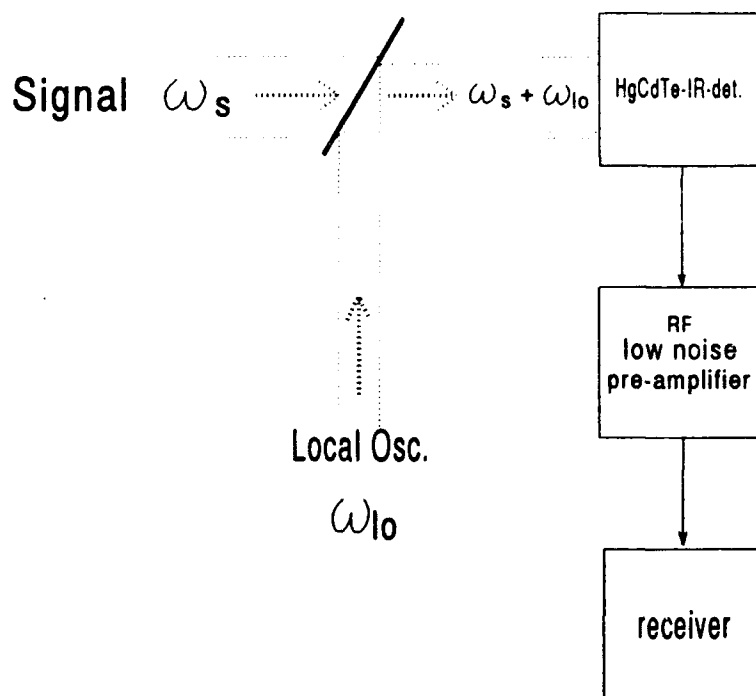pre-amplifier

Local Osc.

ω_{lo}

receiver

Figure 2: Mixing of two coherent optical beams.

Mixing of optical beams begins at the surface of the detector where the signal beam is mixed with a local oscillator beam.

The total field strength of the mixed signal at the detector is:

$$E_t = E_s \cdot \cos \omega_s t + E_{lo} \cdot \cos \omega_{lo} t, \tag{1}$$

where

E_s = field strength of the signal

E_{lo} = field strength of the local oscillator.

Both fields must have the same polarisation and be spatially in phase.

For the IR detector output current i_D we have:

$$i_D = \beta \cdot (E_t)^2, \text{ where } \beta \text{ is a constant of proportionality.} \qquad (2)$$

$$i_D = \beta[E_s^2 \cdot \cos^2 \omega_s t + E_{lo}^2 \cdot \cos^2 \omega_{lo} t + E_s \cdot E_{lo} \cdot \cos(\omega_{lo}+\omega_s)t +$$
$$E_s \cdot E_{lo} \cdot \cos(\omega_{lo}-\omega_s)t] \qquad (3)$$

The last term is of interest for our purpose. When the frequencies of the incident laser beams, ω_s and ω_{lo} at a detector are sufficiently close, a detectable difference (LSB) signal will produce a RF signal, which can be amplified and processed. Since the detector can not detect the very high optical frequencies, these signals are not present. The detector current contains signals proportional to the mean power, which may vary with time.

The resulting detector current will be:

$$i_D = \tfrac{1}{2} \beta[E_{lo}^2+E_s^2] + \beta[E_s \cdot E_{lo} \cdot \cos(\omega_{lo}-\omega_s)t] \qquad (4)$$

The last term is used and selected with a 140 MHz bandpass filter, before FM demodulation.

As a result of mixing, a small signal will be "amplified", if combined with a large local oscillator. This will be limited by the maximum admissible incident local oscillator power at the detector. The maximum S/N-ratio is ideally limited by the signal power (Ps/hv). In practice the S/N-ratio may be limited by the noise from the laser and the noise of the detector-amplifier combination. The noise of the laser-LO should be dominant over that of the detector/ pre-amplifier combination, so the LO-level should be made as high as possible.

In our set-up the frequency difference between the optical beams is obtained with two Acoustic Optic Modulators (see chapter 3.2 above). The output frequency of the IR detector will be of interest at those frequencies at the modulators, in our case at the sum of:

100 MHz + 40 MHz = 140 MHz, which can be amplified easily. The output frequency of the IR detector is linear dependent of ω_s, so will the Doppler frequency as well. It is assumed that ω_{lo} is stable, which is only the case if the laser frequency is stable. Measures has been taken to improve

the stability of the laser. The frequencies at the AOM's are cristal controlled and thus they are stable.

3.2 Vibration detection

Assume that the laser transmits a beam with a circular frequency ω_{opt} to a target, at distance S. The received signal can be described by:

$$\sin(\omega_{opt}t + \varphi), \tag{5}$$

$$\text{where} \quad \varphi = 2\pi \cdot 2S/\lambda = \omega_{opt} \cdot 2S/c \tag{6}$$

The wavelength of the laser is λ.
c is the speed of light $3 \cdot E8$ m/s.

In case a uniformly moving target is hit, the reflection from it is Doppler shifted by an amount:

$$d\varphi/dt = \Delta\omega_{opt} = \omega_{opt} \cdot 2v/c \tag{7}$$

$$v = dS/dt \tag{8}$$

is the radial component of the momentary velocity of the target, i.e. the component which is parallel to the incident laser beam.

A sinusoidally vibrating target will produce a phase modulated signal:

$$\varphi(t) = 4\pi \cdot p/\lambda \cdot \sin \omega_{lf}t \quad \text{and} \tag{9}$$

$$d\varphi/dt = 4\pi \cdot \omega_{lf} \cdot p/\lambda \cdot \cos \omega_{lf}t \tag{10}$$

where p = amplitude of the vibration at the surface of the target and ω_{lf} its frequency.

In practice is $p \gg \lambda$, therefore many periods of the laser wavelength are passed during one period of ω_{lf}.
Frequency demodulation of the $d\varphi/dt$ part (10) is used, because phase detection is not feasible due to phase ambiguities when $p > \lambda$.
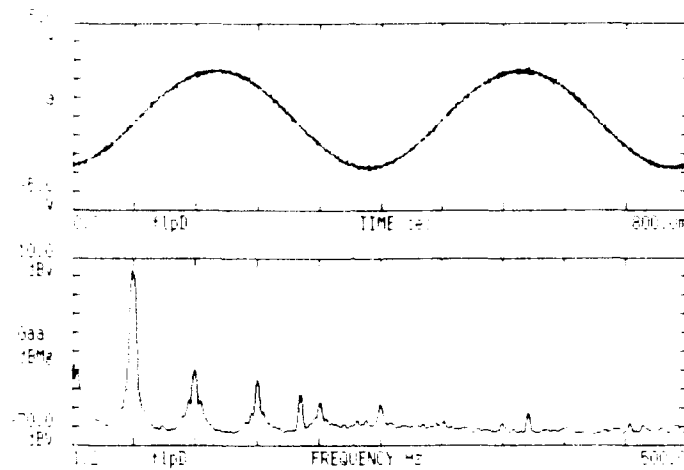
Figure 3:   A demodulated FM signal during an experiment with a vibrating loudspeaker at 300 meters with a frequency of 52 Hz.

In fact, we measure the velocity of the object.

The momentary frequency $d\varphi/dt$ is proportional to the velocity of the vibration and causes a RF bandwidth $B = \Delta f_{RF}$ of the heterodyne RF signal. For this reason the IF bandwidth of the FM receiver has to be adapted for the largest possible RF frequency deviation caused by the vibration.
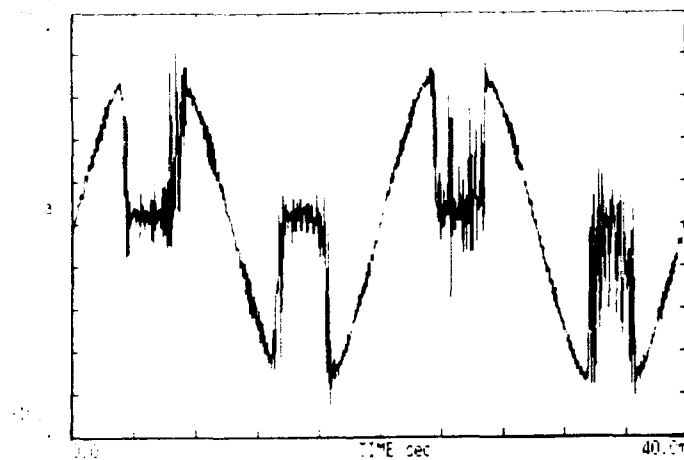

Figure 4:   Setting the IF bandwidth of the FM receiver too narrow causes distortion of the demodulated FM signal.

The amplitude of the targets vibration can be calculated from:

$$\Delta f_{RF} = B = \Delta \omega_{opt} \quad d\varphi/dt = 4\pi \cdot \omega_{lf} \cdot p/\lambda \cdot \cos \omega_{lf}t. \tag{11}$$

The value of the vibrations amplitude p equals:

$$p = \frac{B \cdot \lambda}{8 \cdot \pi^2 \cdot f_{lf}} \text{ (meters)} \tag{12}$$

where B = RF bandwidth in Hz

λ is the laser wavelength in m

f_{lf} is the measured frequency of the vibration in Hz.

3.2.1 Non-linear effects in vibrometry

A brief explanation of the non-linear effects is given below.

A FM receiver has a built-in limiter which suppresses amplitude variations of the RF signal down to the noise level. However, if a target is tilting or wobbling, it will cause (speckle) noise in the FM-demodulated (audio) signal. This is due to the fact that beside a strong amplitude variation (=modulation) there is also a phase modulation of the reflected laser signal or RF signal. This speckle noise will thus be demodulated by the FM demodulator.

Speckle is the result of the reflection of the (coherent) laser light from a non-smooth surface. Most surfaces are rough compared to the laser wavelength of 10.6 µm. The laser beam reflected from different parts of the targets surface causes signals with different amplitudes and phases as a function of position, and will result as a certain field strength at the IR detector. So, in the worst case, the resulting field strength at the detector could be zero, and nothing will be received at all. In practice, this moment will be very short (<few ms) due to movements of the target.
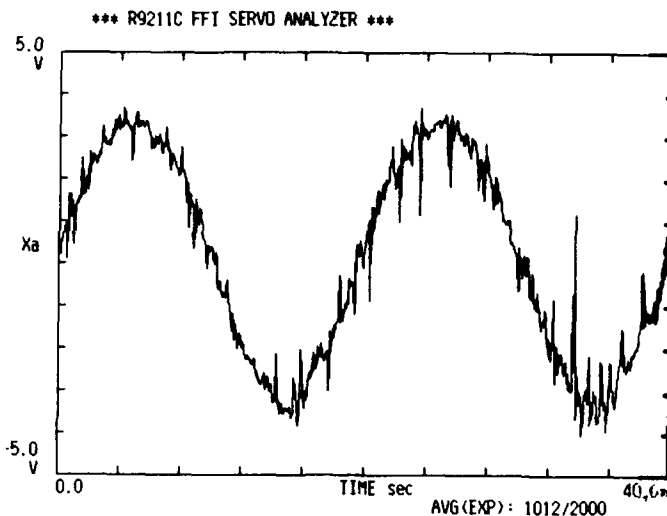
Figure 5: An experiment with a slowly tilting loudspeaker at 300 meters with a tone of 52 Hz shows the influence of the speckle at the frequency demodulated RF signal. The FM receiver IF bandwidth is set to 50 kHz.

Many spots, during a measurement, will pass the IR detector and will cause a phase noise, but also an amplitudinal noise after frequency demodulation. The amplitudinal noise arises when measuring at distant targets. We get small RF signals and a low S/N-ratio at the FM receiver input. In this case, the FM demodulator will produce extra noise in the amplitudinal low-signal moments, because there is no or a too small signal on that particular moment. This phenomenon is known as "FM click noise"[3].

Another effect is interference.

Interference occurs when the laser beam hits two or more different moving reflecting parts. At the RF input of the FM receiver will be more then one RF signal of different frequency.

REF -50.0 dBm   ATT 10 dB   A_view B_blank
5dB/

MKR
140.00066 | MHz
-60.875 | dBm

RBW
300 Hz
VBW
100 Hz
SWP
1.4 s

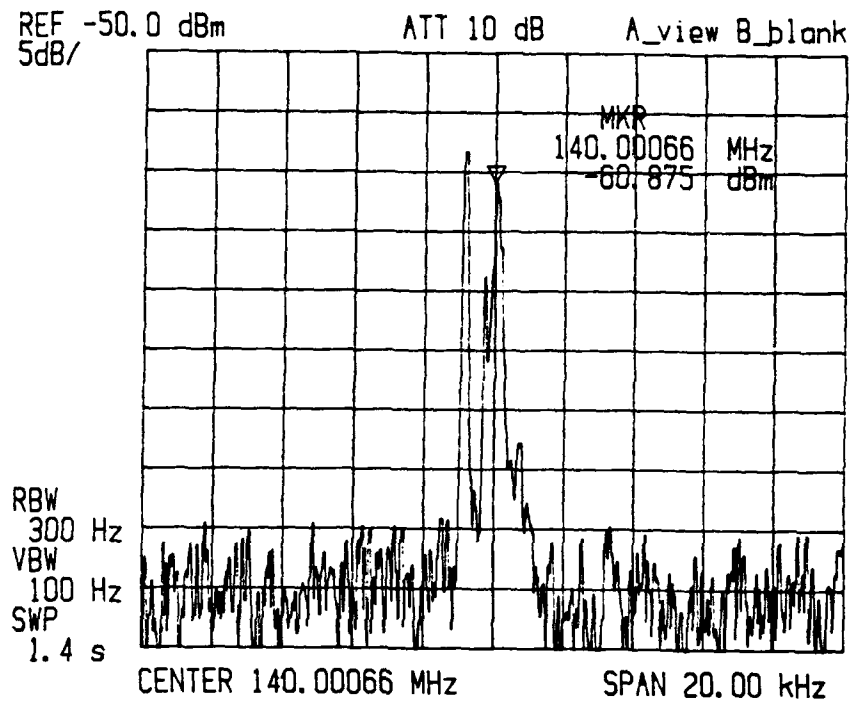CENTER 140.00066 MHz   SPAN 20.00 kHz

Figure 6:   Experiment with a loudspeaker at 300 meters with a 2.5 Hz slowly moving cone and background reflection. The frequency of the background signal stays at 140 MHz, while the other spike, caused by the cone, moves around 140 MHz as a function of time; in this example with a deviation of about 2 kHz, depending on the velocity of the cone.

After FM demodulation a chirping signal component will be added at the desired vibration signal[1].

For instance, if we take only two reflecting parts, a vibrating (A) and a non-vibrating part (B), this can be described by:

$$A \cdot e^{j\theta_A(t)} + B \cdot e^{j\theta_B(t)} = C \cdot e^{j\theta_C(t)} \tag{13}$$

where A and B are the amplitudes of the reflected components and C is the amplitude of the resulting signal.

We define:

$$\omega_{opt}t + \varphi_1(t) = \theta_A(t), \tag{14}$$

$$\omega_{opt}t + \varphi_2(t) = \theta_B(t), \tag{15}$$

$$\omega_{opt}t + \varphi_3(t) = \theta_C(t) \tag{16}$$

$$\varphi_1(t) = \theta_A(t) - \theta_B(t), \tag{17}$$

$$\varphi_2(t) = 0 = \text{constant phase (non vibrating)}, \tag{18}$$

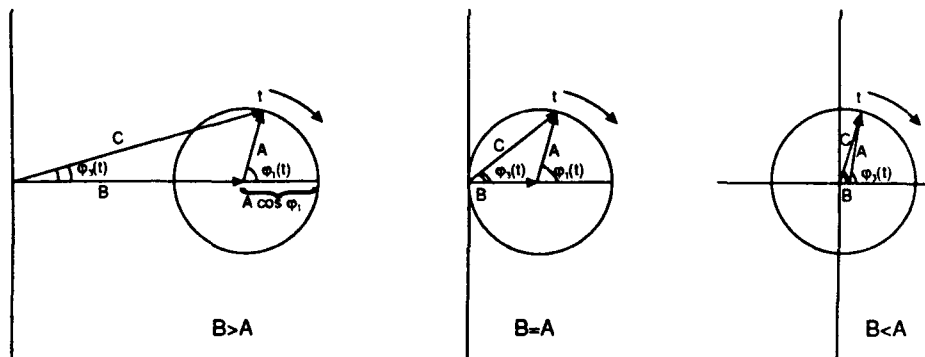$$\varphi_3(t) \quad \theta_C(t) - \theta_B(t) \tag{19}$$

Figure 7:   The vectorial presentation shows the influence of the reflected signals A (vibrating object) and B (non-vibrating object) at the amplitude and the phase of the resulting signal at the FM receiver input. Assume $\varphi_2(t) = 0$. Vector A rotates with $4\pi \cdot p/\lambda \cdot \sin \omega_{tr}t$.

Substitution of (17), (18) and (19) in (13) yields:

$$\varphi_3(t) = \text{arctg} \frac{A \cdot \sin \varphi_1 t}{B + A \cdot \cos \varphi_1 t} \tag{20}$$

So, in general the detected phase is a non-linear function of the actual phase, even in case of $\varphi_2 = $ constant.

For example, four situations for the FM demodulator can be assumed:

1) if B<<A then $\varphi_3(t) \approx \text{arctg} \dfrac{\sin \varphi_1 t}{\cos \varphi_1 t} = \varphi_1(t)$ (little distortion)　　　　(21)

2) if B=A then $\varphi_3(t) = \text{arctg} \dfrac{\sin \varphi_1 t}{1 + \cos \varphi_1 t} = \tfrac{1}{2} \cdot \varphi_1(t)$　　　　(22)

3) if B>>A then $\varphi_3(t) \approx \dfrac{A \cdot \sin \varphi_1 t}{B} = $ (distorted signal)　　　　(23)

4) if B $\approx$ A $\neq$ B,　　　　(24)

then the amplitude of the noise spikes at the output of the FM demodulator are depending on the vibration amplitude p.

$$\dot{\varphi}_3 = \frac{A(A + B \cdot \cos \varphi_1(t))}{(A^2 + B^2 + 2AB \cdot \cos \varphi_1(t))} \cdot \dot{\varphi}_1(t)$$　　　　(25)

if $\cos \varphi_1 = \pm 1$ then $\dot{\varphi}_3 = \dfrac{A}{A + B} \cdot \dot{\varphi}_1$　　　　(26)

if $\cos \varphi_1 = 0$ then $\dot{\varphi}_3 = \dfrac{A^2}{A^2 + B^2} \cdot \dot{\varphi}_1$　　　　(27)

An experiment with a loudspeaker and some simulations, using (25), shows the effect of interference at the desired vibration signal.
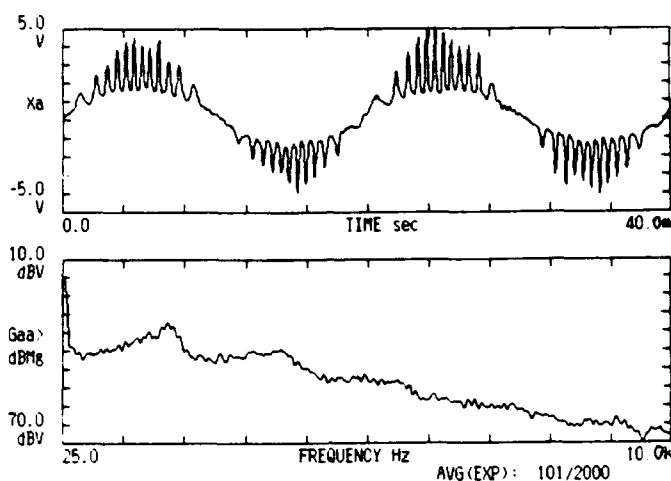
Figure 8:   Experiment. Demodulated FM heterodyne signal and its averaged power spectrum caused by
a reflection of about 25% of a non-vibrating part and 75% of a vibrating loudspeaker. The
frequency at the loudspeaker is 52 Hz. The vibration amplitude "p" of the cone is about
32 µm (p=3). The bandwidth of the FM receiver is set to 6.4 kHz. The frequency range of
the interference with the harmonics, in the power spectrum, is depending on the amplitude
"p" of the vibration and is in this example mainly outside the frequency band of interest 5-
500 Hz, where the strongest vibration amplitudes can be found. With small values of "p"
(near λ) the interference can fall inside the band of interest.

In the next three simulations (figures 9-11) the values of "A" and "λ" are normalized to 1. The
amplitude ratio of "B/A" of the reflected parts and the amplitude "p" of the vibration are varied.

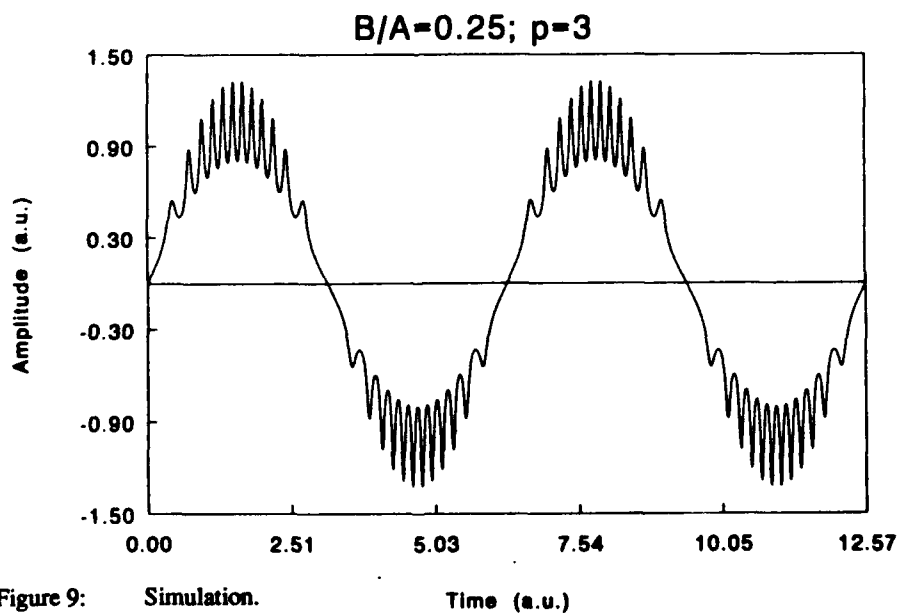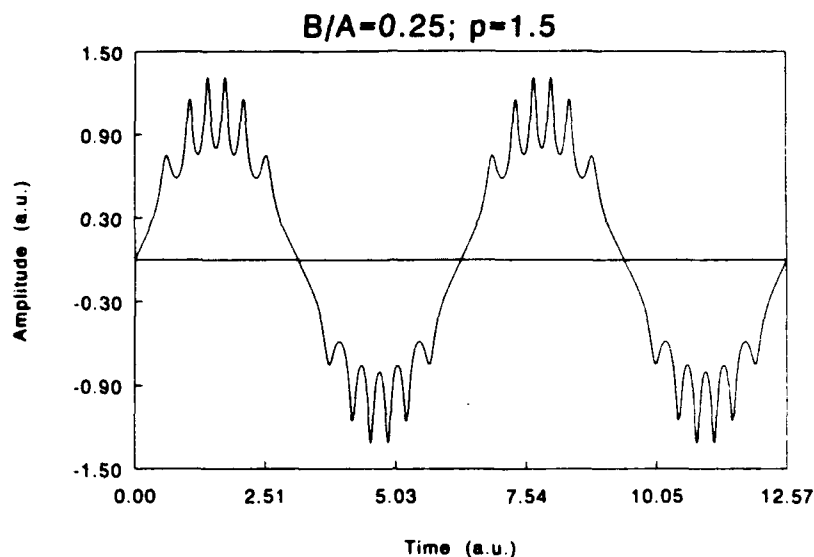Figure 9:   Simulation.   Time (a.u.)

B/A=0.25; p=1.5

Figure 10:   Simulation. Decreasing the vibration level "p".
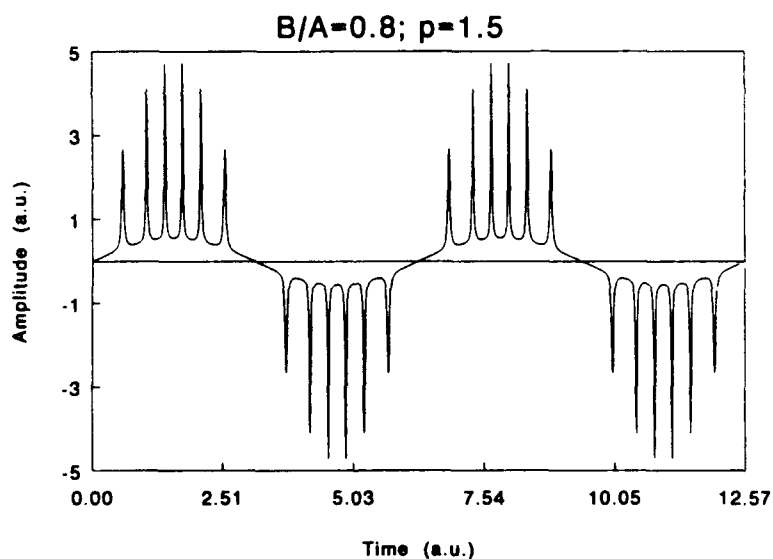
B/A=0.8; p=1.5

Figure 11:   Simulation. Increasing the background level "B".

For vibrating objects the situation is in general more complex, because the vibration will be non-uniform, the more so for distant targets. We get a complex non-linear mixture of all time dependent phases, causing special effects on the audio output signal.

These effects on the signal and the S/N-ratio are studied in depth by Dr. A. Henstra in a report[3].

From this study we know now that if the *target or laser beam is continuously moving*, there is an additional dynamic speckle effect. The (cross) harmonics caused by FM demodulation are "wiped out", and in the power spectrum, only the pure vibration signal of the target is left.

This is the case with our measurements; the helicopter is continuously moving. The measured frequencies in the spectra therefore are caused by the helicopter itself.

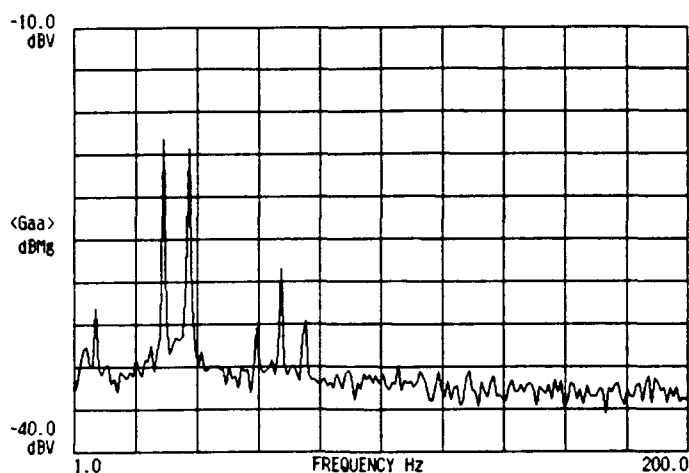

Figure 12:   Averaged power spectrum of the demodulated FM signal in an experiment with two loudspeakers vibrating at frequencies of 30Hz and 38Hz. Cross frequencies appear. (courtesy A. Henstra).
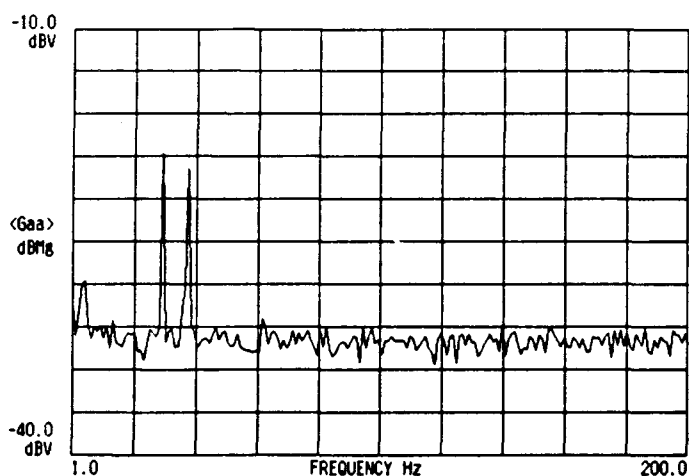

Figure 13:   Ditto as in figure 12, but now both loudspeakers are slowly tilting with an angular velocity $\omega_{tilt} \approx 0.14$ rad/s. Cross frequencies disappear. (courtesy A. Henstra).

During tilting of a vibrating object, due to FM clicks, the measured AF noise level after FM demodulation is rising and is the highest in the lower part of the spectrum (1/f-noise) and is depending of frequency of the vibration.[3] This is clearly visible if a larger span is used of e.g. 10 kHz.

The mass, suspension and absorbers etc. of a vibrating object defines the cutoff frequency. In practice, the strongest amplitudes of the measured vibrations lies in the lower range of the audio spectrum 0-200 Hz. Due to the fast reduction of vibration amplitudes, with distance from the source, of higher frequencies, these can only be detected when the beam is pointed very near to the vibration source.

Doors, plates and other "loose" objects resonate and produce strong amplitudes of the spikes in the frequency spectrum.

4 THE VIBRATION SOURCES OF A HELICOPTER

To understand the cause of the vibrations of a helicopter, a brief description of the machinery is presented. The figure on the next page depicts a simple outline of the transmission system of the Alouette III (type SA.3160) and his vibration frequencies.

The strongest vibrations are caused by the main rotor and by the tail rotor (both have 3 blades). The rotor blades etc. are never in perfect balance and certainly not for every flight situation e.g. the flight or the hover situation. So, the helicopter will always vibrate. To avoid that the vibrations become too strong, the rotor blades have to be tuned. Since 1988, the maintenance group of the "Koninklijke Luchtmacht" at Soesterberg uses computerized "Rotortuners" from Helitune[6].

Periodically, during maintenance, vibration checks are carried out with accelerometers, sensitive for vibrations in the axial and lateral direction. They are positioned very near to the rotors. Accelerometers are also positioned near the pilot-seat and/or on the cabin's roof for the vertical and the lateral directions.

The engine number of revolutions is stabilized within 33400-33600 RPM i.e. 0.6 percent and is normally adjusted at 33500 RPM. (558.33 Hz).

The rotation of the main rotor axis is indicated by 1R. The frequency of it for the Alouette III is ≈ 5.88 Hz. Here are three rotor blades. Every single blade of the main rotor delivers a certain trust and is cyclical tilting during every rotation, which is needed for steering, thereby producing 3R vibrations. So, there will be a lot of turbulence because of the rotors and the helicopter itself and many mechanical reaction forces will push and pull the helicopter. Lift force variations, because of wrong adjustment of the tilt-angle of the blades or unequal torsion in the blades, will cause mainly axial vibrations at frequency 1R.

main rotor

R: main rotor frequency
2nd stage plantary gear

5,88 Hz

16,6 Hz

46,9Hz

96,15 Hz

1st stage
planetary
gear

bevel gear
assembly

main gear box

engine
558,3 Hz

96,2 Hz

tail rotor drive shaft
39,85 Hz
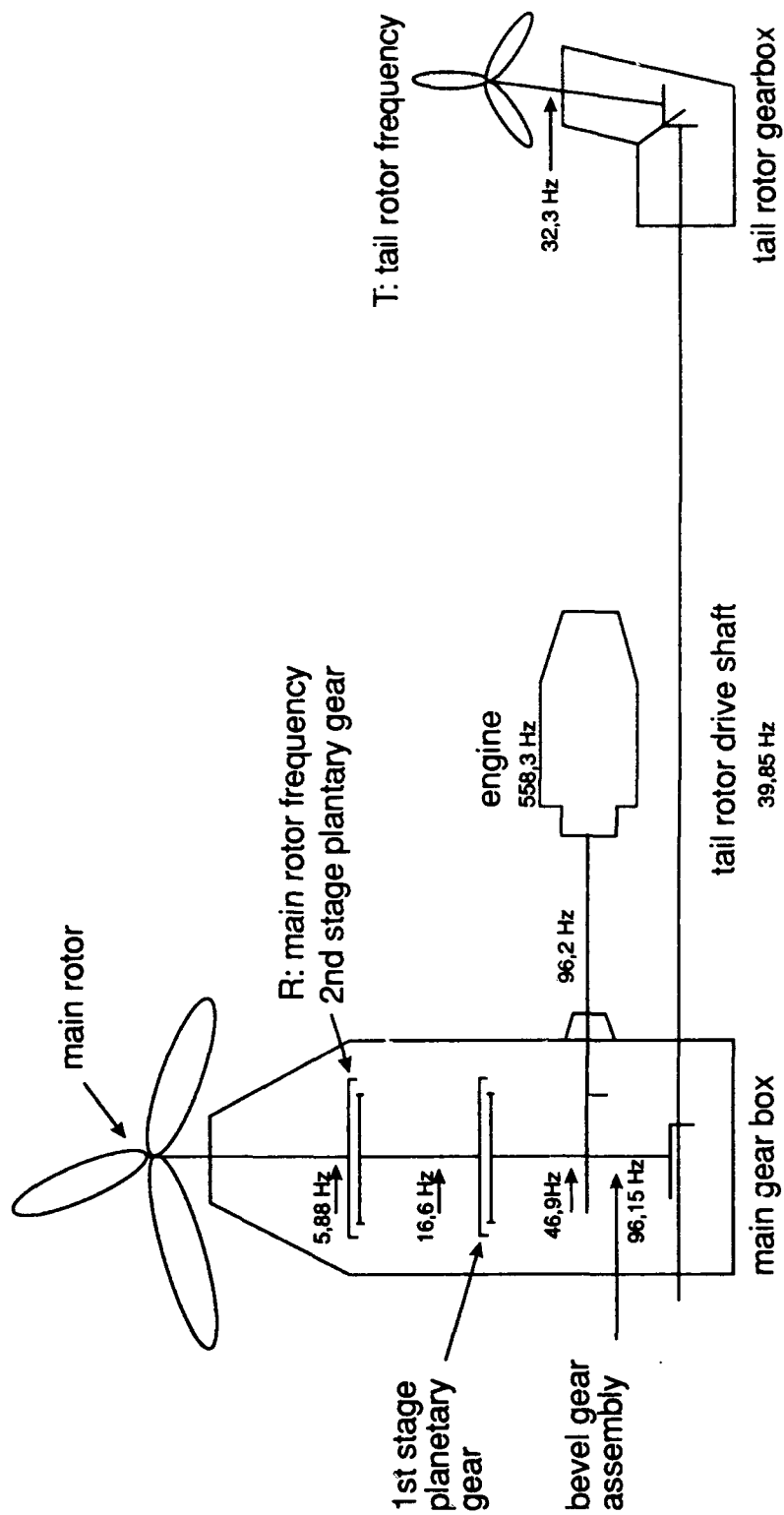
T: tail rotor frequency

32,3 Hz

tail rotor gearbox

Figure 14:   Outline of the Alouette III.

Difference of weight (unbalance) of the blades will cause a vibration in the lateral direction at frequency 1R. Changes in blade spacing (lead/lag) and track will also cause vibrations.

The same can be said about the tail rotor, except that there is no cyclical tilt of the blades during every rotation. The rotation of the tail rotor axis is called 1T. The frequency of it is $\approx$ 32.27 Hz for a Alouette III.

An enumeration of adjustable by maintenance R and T vibration causes are for example:

- Wrong tilt adjustment of the blades and trimtab.

- Main rotor head in unbalance.

- Drag dampers out of time.

- Main rotor head rough (dragging/flapping hinge bearing).

- Main rotor spacing cables don't have the correct length.

- Swash plate has too much play.

- Trust bearing main rotor shaft has too much play.

- Brake disk of the rotor brake not correct in centre.

- Tail rotor blades in unbalance.

- Too much play in the tail rotor shaft/ tail rotor gearbox bearing.

- Too much play in the coupling shaft.

- Rear engine bearing too much play, etc.

It happens that the amplitude, measured with the rotortuner, of some vibration spikes, mainly the R and T spikes, can be reduced to a factor five or more after tuning. See figure 15 below.
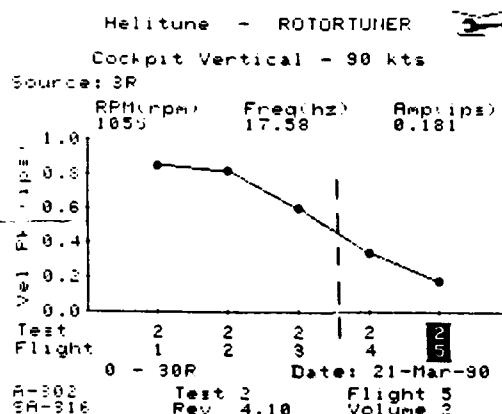

Figure 15:   Vibration levels after five successive adjustments.
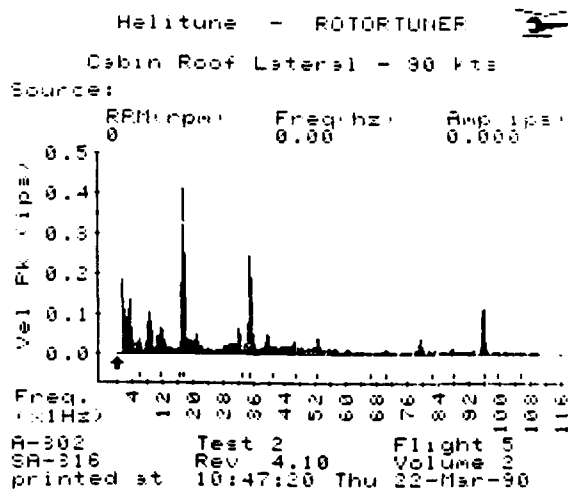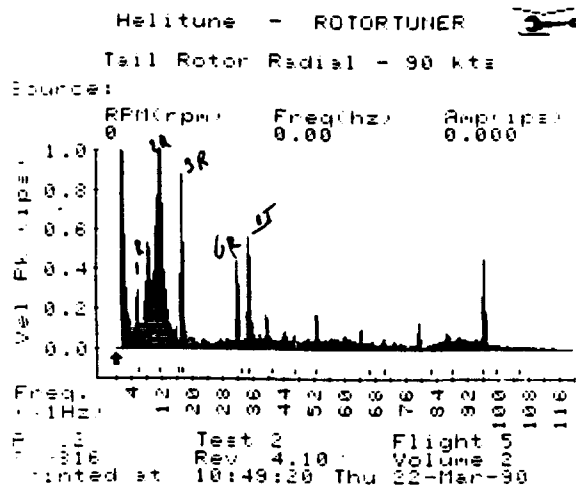
Figure 16: Some graphs from the helituner.

Not only the R and T spikes are present but also for example:

- The main rotor gearbox (MRGB)
- The engine gas producer (GP)
- The tail rotor driveshaft (TRDS)
- Meshing tail rotor gearbox (MTRGB)
- Lower bevel gear, (LBG) etc..

```
Tape Contents:                         .

-------------- Test 1 ---------------

Flight 3 saved at 10:54 on 06-Mar-91
  Track, Balance, Settings,  -
        Vibration Signatures:
  Cockpit Vertical
   90 Hts :   ,100 ,    .   .    .


A-319      Test 1      Flight :
SA-316C    Rev  4.15   Volume :
printed at  15:14:20 Thu 12-Sep-:

        ROTORTUNER Order Sheet
        ---------- ----- -----


                        Frequency
                        ---------
Description:            (<1P): (>1Hz):
-----------            ------  -------


1P
.................... 1.00    5.89          <------

2P
.................... 2.00    11.77         <------

1+ First Stage Epicyclic
.................... 2.82    16.60

3P
.:.................. 3.00    17.65         <-----
1T.................. 5.48    32.27         <-----
6P
.................... 6.00    35.30         <----

1+ Tail Rotor Drive Shaft
.................... 6.77    39.85 TDRS    <------


MRGB Vertical Drive Shaft
.................... 7.97    46.90 VDS     <------

9P
.................... 9.00    52.95

2T
.................... 10.97   64.55

12P        .
.................... 12.00   70.60

2+ Tail Rotor Driveshaft
.................... 13.55   79.74 2 TDRS  <------

15P
.................... 15.00   88.25         <-----

1+ Engine Output Shaft
.................... 16.34   96.15

1+ Input Bevel Gear
.................... 16.34   96.15

3T
.................... 16.46   96.82         <-----

18P
.................... 18.00   105.90        <-----

6T
.................... 32.91   193.64        <-----

9T
.................... 49.37   290.47        <-----

1+ Gas Producer
... ................ 93.37   549.30 GP     <-----

1+ Meshing Tail Rotor Gearbox
.................... 115.20  677.76 MTRG   <------

M. Lower Bevel Gear
.................... 135.53  797.37 LBG    <------

M. First Stage Epicyclic
.................... 144.02  847.29

M. Input Bevel Gear
.................... 326.87  1923.07


A-319      Test 1      Flight 3
SA-316C    Rev  4.15   Volume 1
printed at  14:41:49 Thu 12-Sep-91
```

Figure 17:   The rotortuner sheet: Frequency list of vibrations of the Alouette III SA.3160, registration
              sign A319. All marked frequencies are also measured with our laser system at large
              distances and matches perfect with the rotortuner data of the Dutch Air Force in Soesterberg.

5   MEASUREMENTS

5.1   Measuring Method

The laser beam was aimed at all parts of the helicopter, except the rotor blades, because these blades produce very large Doppler shifts, which could not be handled by our FM demodulation method.

The 140 MHz heterodyne signal coming from the IR detector, of the CO_2-laser system set-up, is sent to a FM receiver with an adjustable bandwidth. As mentioned in chapter 4.2, the adjustable bandwidth is required because the RF bandwidth of the 140 MHz FM signal is dependent of the vibration level of the target.

The receiver has the following available bandwidths: 1 MHz, 120 kHz, 12 kHz and 7.5 kHz. In practice the 120 kHz bandwidth is the best fit for helicopter measurements.

Also I measured the RF bandwidth with an Advantest 3361A spectrum analyser, in order to adapt our receiver bandwidth, avoiding signal distortion. The maximum measured RF bandwidth amounts to $B \approx 100$ kHz.

The $1R = 5.88$ Hz vibration causes probably the largest RF bandwidth. The amplitude of the vibration (chapter 3.2.1 using form (12)) at the helicopter hull will be for this frequency:

$$p = \frac{B \cdot 1}{8 \cdot \pi^2 \cdot f_{lf}} \approx 2.25 \text{ mm max.}$$

For land-vehicles a smaller FM receiver bandwidth of 12 kHz, 7.5 kHz or less can be used. The amplitude p of those vibrations lies near approx. 0.1 mm.

The R&S receiver has a AFC-mode (Automatic Frequency Control) option which was used because the received signal could fall outside the detection bandwidth of the FM receiver due to the target's movement. This AFC compensates the Doppler shift for small movements of the helicopter. To carry out measurements during flight was difficult because of missed RF signals; the receiver's AFC could not handle the accidently received noise, so de-tuning took place.

The SA.3160 has a cruise speed of 115mph (185 km/hr). For instance, this speed causes a Doppler shift of:

$$f_D = 2 \cdot v \cdot f_{opt}/c = 2 \cdot v/\lambda = 2 \cdot 51.39 / 10.6 \cdot E\text{-}6 = 9.7 \text{ MHz at 140 MHz!}$$

Therefore, a sophisticated RF scanning (tuning) system in the receiver, eventually coupled with a (semi) real time electronical-optical RF spectrum analyser, finding and tracking small signals in the noise, is necessary for this purpose. The latter analyser has been made several years ago at TNO-FEL and could be used for that purpose.

The mirror had to be controlled manually. Although I used a handy trackball to control the mirror, I still had problems to track the helicopter in flight.

In practice, a video tracking system which is connected to the scan-mirror is necessary for this application.

The audio signal from the FM receiver was recorded with a Nakamichi cassette deck and analysed afterwards with an Advantest R9211C FFT frequency analyser.

The audio signal is analysed with different spans of 0-10 kHz, 0- Hz, 0-1 KHZ and 0-200 Hz.

The accuracy of the measured frequencies depends on the number of FFT points. The Advantest R9211C can be adjusted from 25 to 3200 points. We used 200, 400 or 800 points.

The time needed for a FFT measurement depends also on the number of points, the frequency range of the measurements and a number of other settings of the FFT analyser. Features of the analyser's processor, like auto scaling etc., are time-consuming. In general an estimation of the power spectrum with 200 points within a frequency range of 1-200 Hz can be carried out within one second. During that time, the analysing device already uses a kind of averaging during acquisition. Using the averaging mode, a measurement takes longer. The FFT analyser is also capable of making waterfall displays, or "3D-images", so that changes with time of the spectrum can be observed. In our case I used a timespan of about 10-45 seconds.

From waterfall display measurements it appeared that during longer periods, from a few seconds to a minute, some of the spikes in the spectrum showed regular amplitudinal variations, or disappear and reappear. This has to do with the fact that the laser beam could not been held at the same place on the surface of the target.

5.2   Scenario and measurements at various distances and angles

Scenario:

At all ranges the hovering helicopter was positioned at four angles with respect to the front side of the helicopter and the laser system: 0°(front), 45°(left), 90°(left) and 180°(tail).
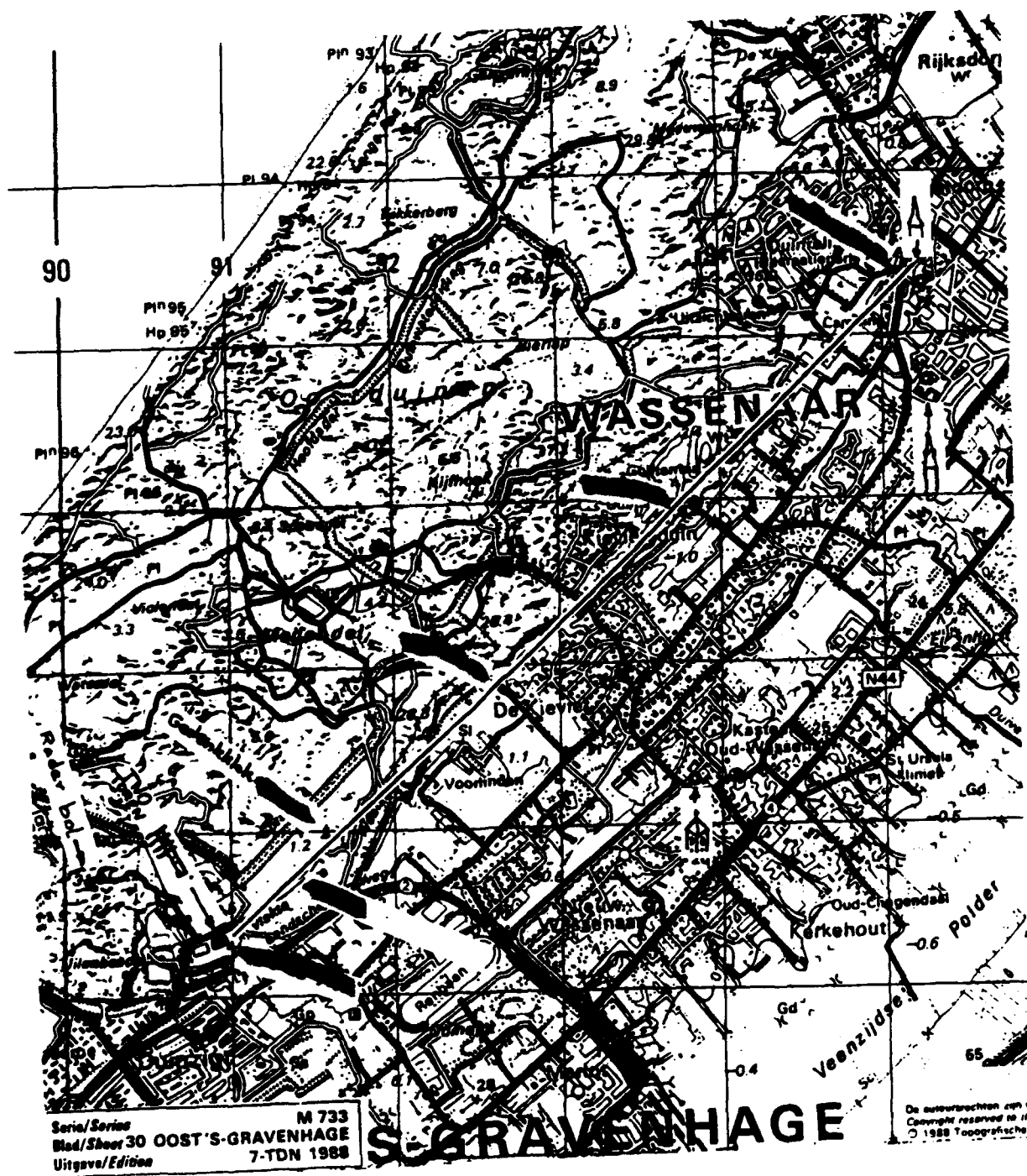
Position A, altitude ≈ 300ft., distance ≈ 500m

Position B, altitude ≈ 400ft., distance ≈ 900m

Position C, altitude ≈ 800ft., distance ≈ 2400m

Position D, altitude ≈ 1000ft., distance ≈ 4000m

Position E, altitude ≈ 2000ft., distance ≈ 6000m

A selection of the collected data will be discussed next.

Figure 18:   Map of the test-side.

5.2.1   Helicopter at a distance of 500m (position A) at 0° angle.
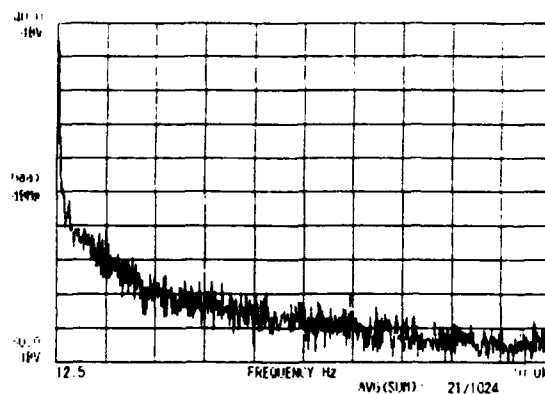
Figure 19: The avreraged frequency spectrum 0-10 kHz during 4 seconds.
Note the 1/f-speckle noise.

Photo 4: 0° angle.
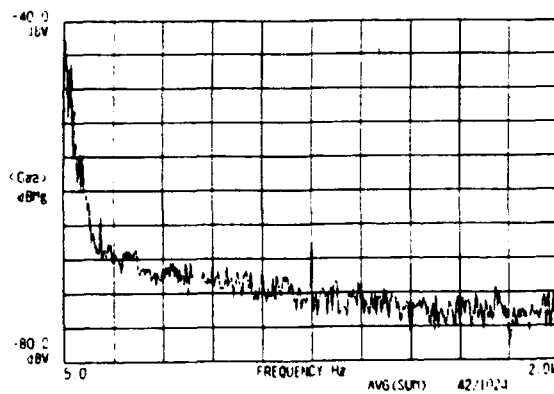
Figure 20: Zoomed in to 0-2 kHz.
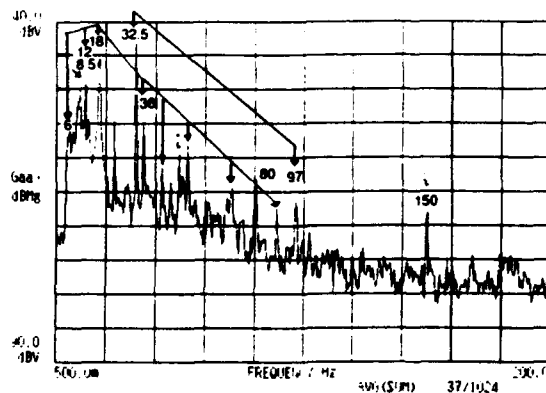
Figure 21: Zoomed in to 0-200 Hz.

Figure 22: 3D waterfall during 20 seconds.

At 0° angle of the helicopter, we see only strong signals in the 0-200 Hz region, depending of the part of the helicopter where the beam is aimed at: in this case, the bottom of the cockpit. See graphs 19, 20, 21 and photo 4.

The frequency spectrum in the range of 0-200 Hz of graph 21 and 23 shows distinctive spikes caused by some of the many vibrating parts of the helicopter.
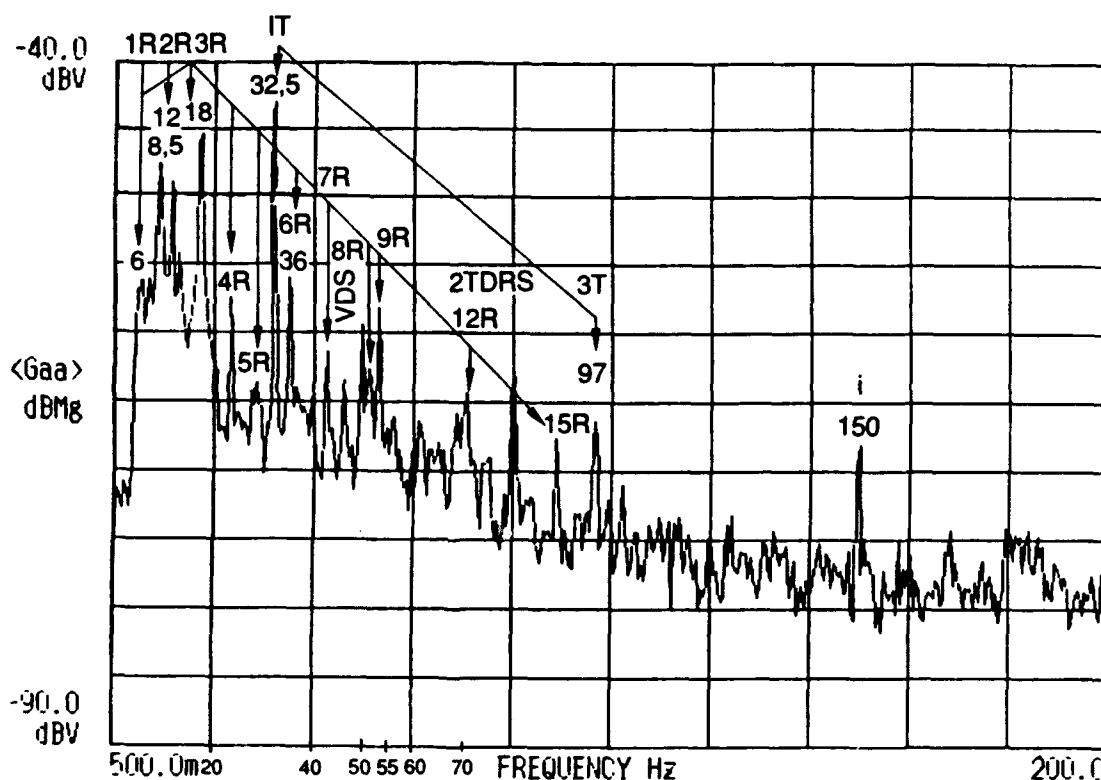

Figure 23:   Position A at 500 m, 0° angle (cockpit). In this graph 37 spectra are averaged during 7 seconds.
R = main rotor, T = tail rotor, 2TDRS = tail rotor drive shaft, VDS = MRGB vertical drive shaft, i = mains hum interference.

The 1T spike at 32.27 Hz is the strongest and points to an unbalance of the tail rotor in the lateral direction. The 3T spike is visible at 96.81 Hz.

The 3R spike at 17.65 Hz is also very strong and many harmonics of the main rotor (R) are visible. The spike at 46.9 Hz points to the vertical drive shaft (VDS) of the main rotor gearbox, and the spike at 79.7 Hz is the second harmonic of the tail rotor drive shaft (TDRS).

5.2.2　　　Helicopter at a distance of 500m at 45° and 90° angles.

The laser beam was aimed at about in the centre of the helicopter.

Viewing at another angle makes it possible to see vibrations occurring in other directions. Clearly visible at graphs 22, 23 and 24, is that the amplitude ratio's of the harmonics change with angle aspect of the helicopter.
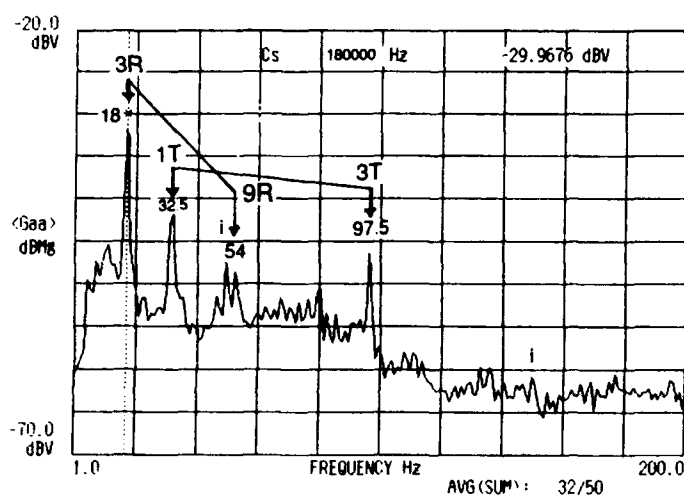

Figure 24:　Position A, 45° angle.　　　　　　Photo 5:　Position A, 45° angle
　　　　　　Mainly the 3R, 1T and 3T spikes.
　　　　　　The 1R and 2R spikes are
　　　　　　significant smaller now.

Because the laser beam was aimed slightly to the right, i.e. the tail side of the helicopter, more vibrations coming from the tail rotor are measured now. The 1T and 3T spikes are very distinctive. The Drive Shaft of the tail rotor (TRDS) shows a strong second harmonic at about 80 Hz.

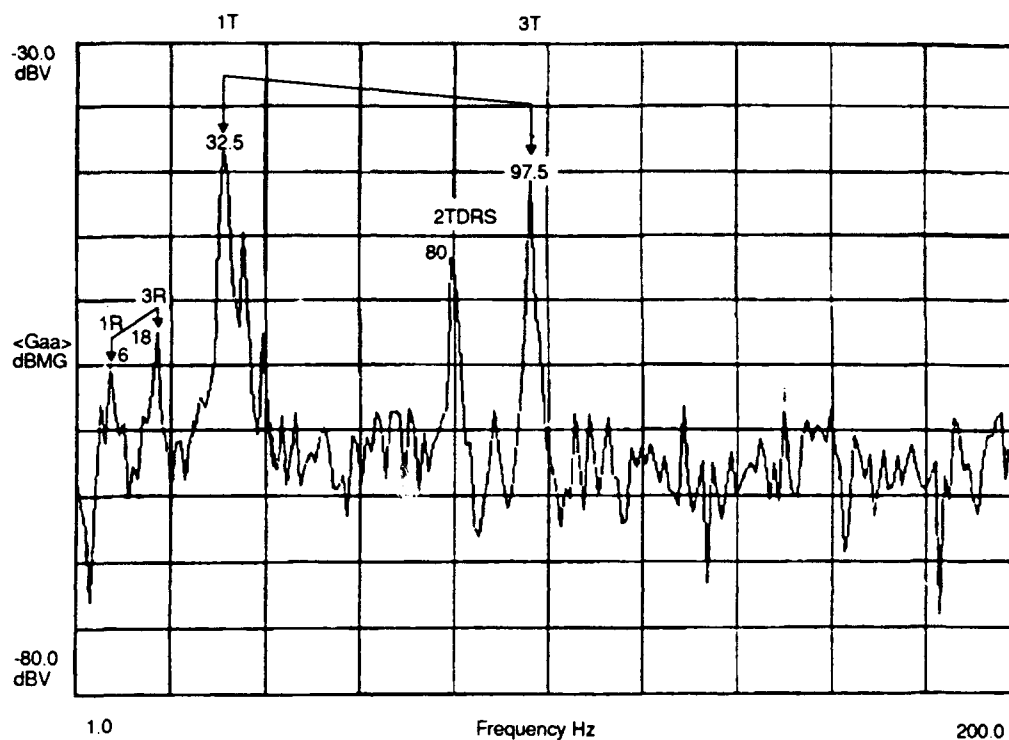Measurements were usually carried out with the FM receiver set at an IF bandwidth of 120 kHz.

Figure 25: 90° angle, left side at position A at 500 m. IF bandwidth 120 kHz. Averaged during 5 seconds.

In one case, a IF bandwidth of 1 MHz was chosen, in order to look for strong vibrating parts, leading to large bandwidths. The change had little effect, except that the noise level increased and the small hum interference spikes at 50 Hz and 150 Hz were hardly visible anymore. A longer averaging time for the FFT analyser was used to obtain a cleaner graph.
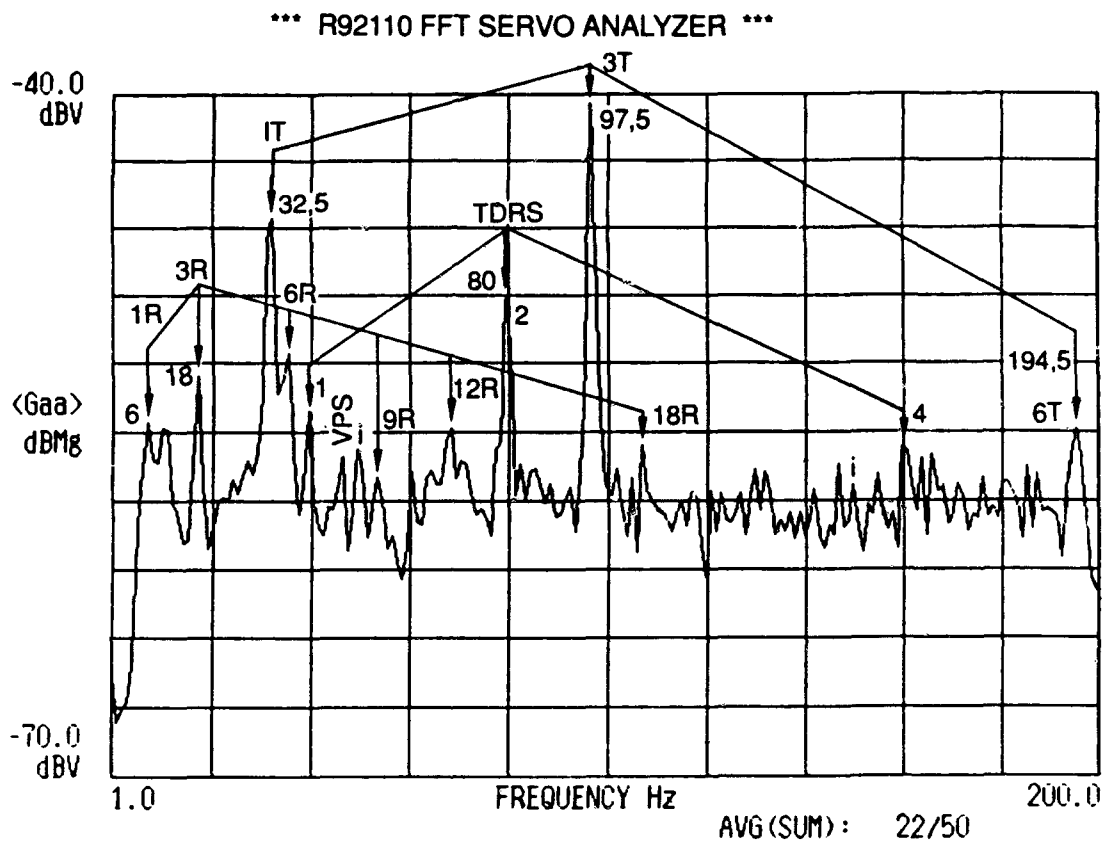
Figure 26: The 90° left side at 500 m: vibration detection with 1 MHz IF bandwidth shows the following spikes: 1R, 3R, 6R, 9R, 12R, 18R, 1T, 3T, 6T, 1TRDS (Tail Rotor Drive Shaft), 2TRDS, and 4TRDS.

5.2.3 Helicopter at a distance of 900m (position B) at 90° and 180° angles

Figure 27 (angle = 90°) shows strong 1T, 3T, 1R, 6R spikes and again the spike from the tail rotor drive shaft. The 1R spike becomes larger now. This can be caused by unbalance of the main rotor. Due to the variation of the strength of the vibrations on the surface of the target as a function of place, some vibrations could be better detected at some other angles. Standing waves could cause maxima and minima of the vibrations at the surface of the helicopter. The construction of a helicopter is not so stiff as one may assume. An interference hologram (i.e. a hologram which is obtained by two short exposures) could make that perfectly visible.
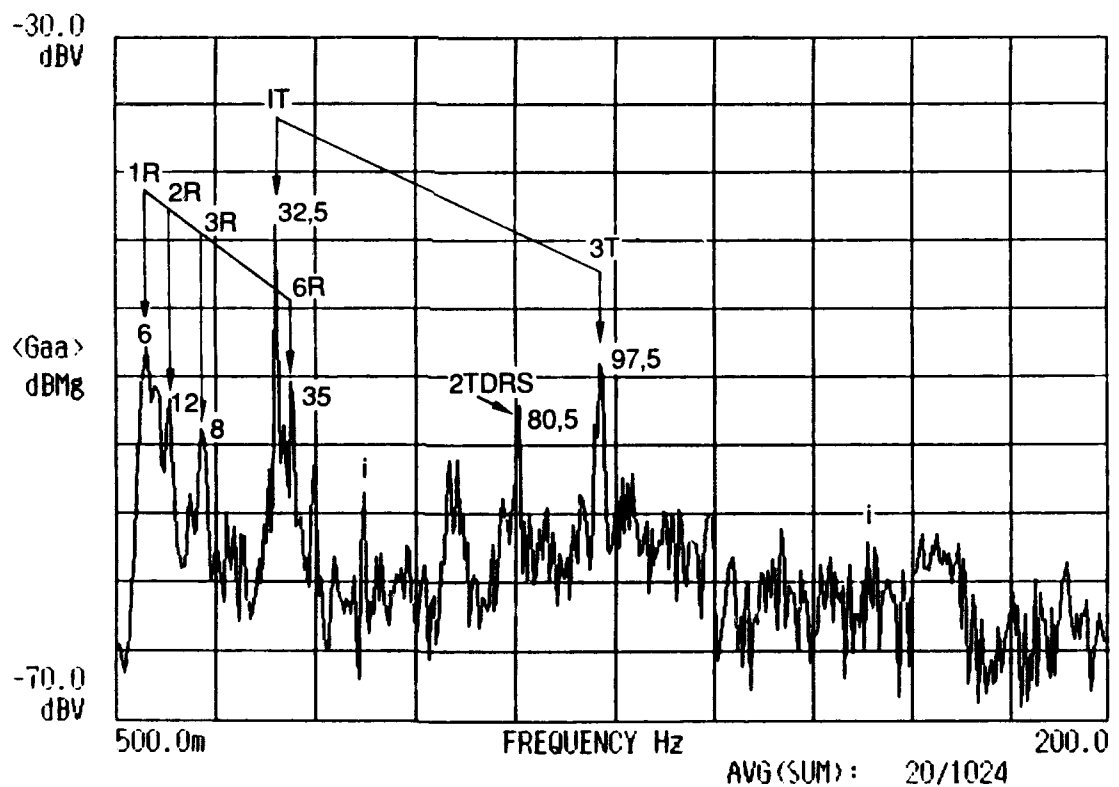
Photo 6:   Alouette III at 900 m.

Figure 27:   90° angle at 900 m. Graph shows strong 1T, 3T, 1R, 6R spikes and again the spikes from the tail rotor drive shaft. Averaged over 5 seconds.
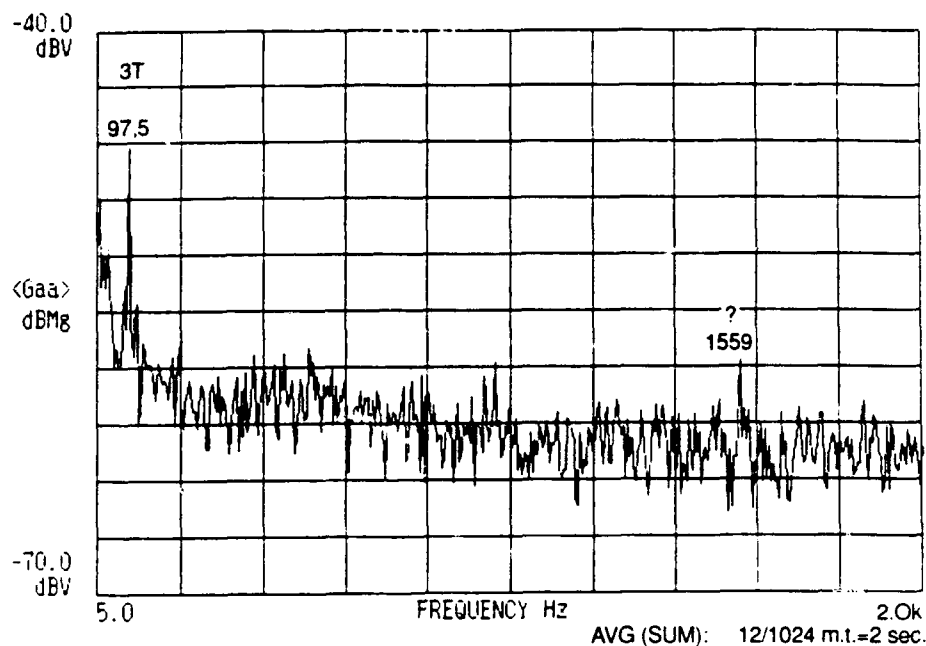
Figure 28: 180° angle (tail), at position B at 900 m. The laser was pointed at the underside and landing gear. Only 3T at 97 Hz and some minor spikes are visible. The spike at 1559 Hz is of an unknown source (not listed in the Rotortuner sheet), but is measured with the accelerometers as well.
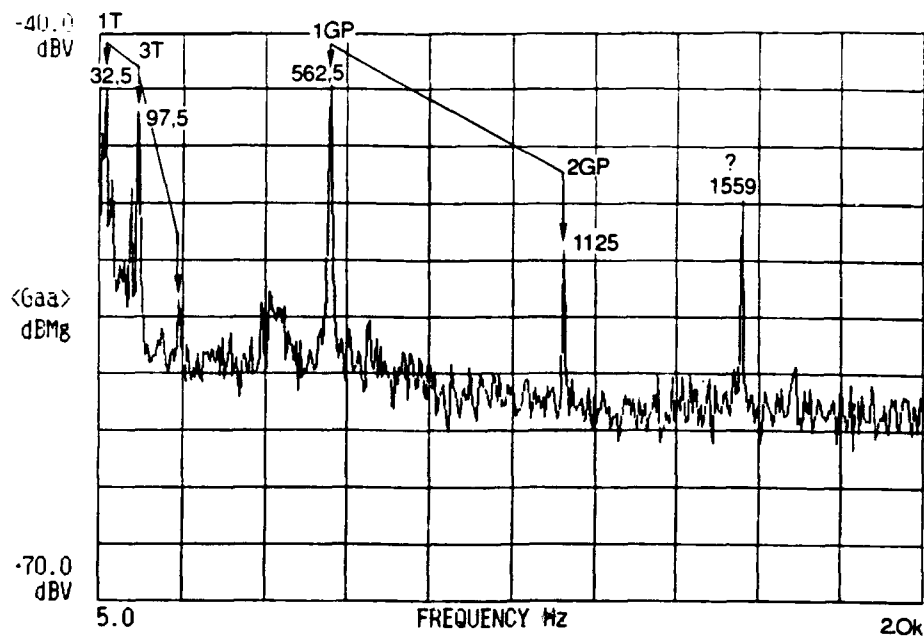

Figure 29: Ditto as fig. 28. Now the laser is pointed at the tail. There are many spikes: 3R, 1T, 3T, 6T, the 1GP (Gas Producer) at ≈550 Hz and 2GP at 1100 Hz, the 1MTRG (Meshing Tail Rotor Gearbox) at ≈680 Hz.

*** R9211C FFT SERVO ANALYZER ***
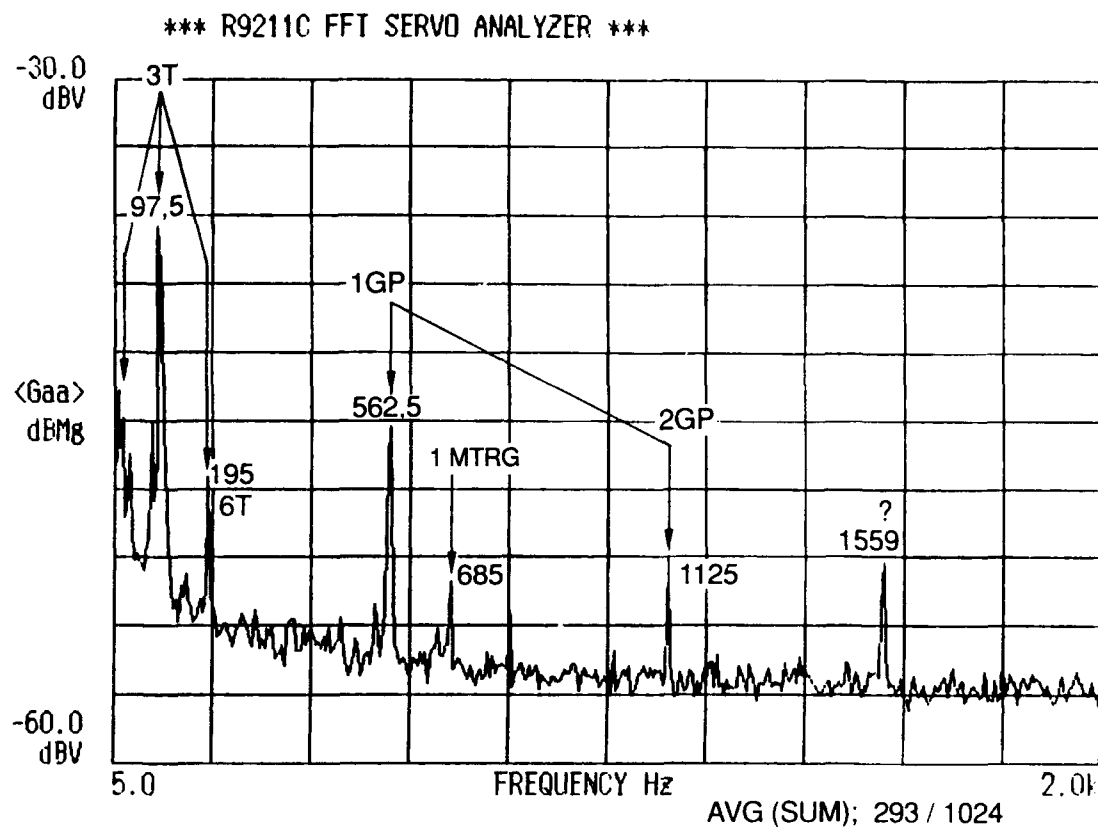

Figure 30:   This graph shows an average during 1 minute of the signal of figures 28 and 29.

5.2.4   Helicopter at a distance of 2.4 km (position C) at 90° and 180° angles

Photo 7:   Alouette III at 2.4 km.

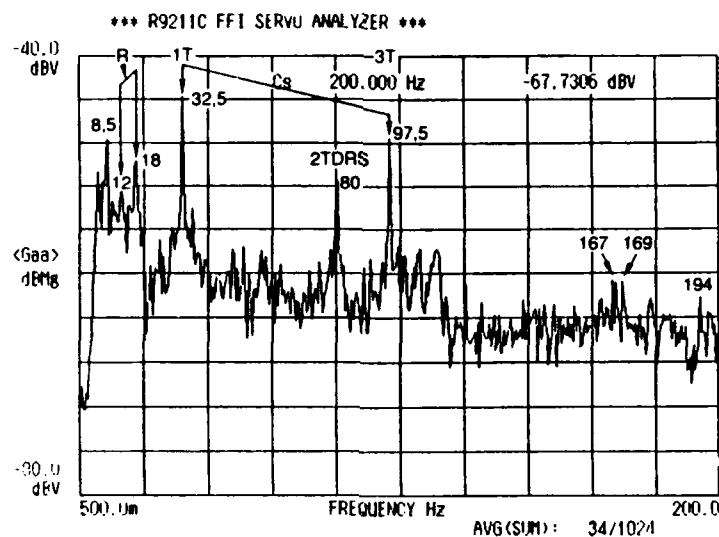*** R9211C FFT SERVO ANALYZER ***

Figure 31:   90° angle at position C at 2400 m. Here again the 1T, 3T, 6T, 2R, 3R and 2TDRS spikes.

The figures 32 and 33 show the 180° tail vibrations at position C at 2400 m.
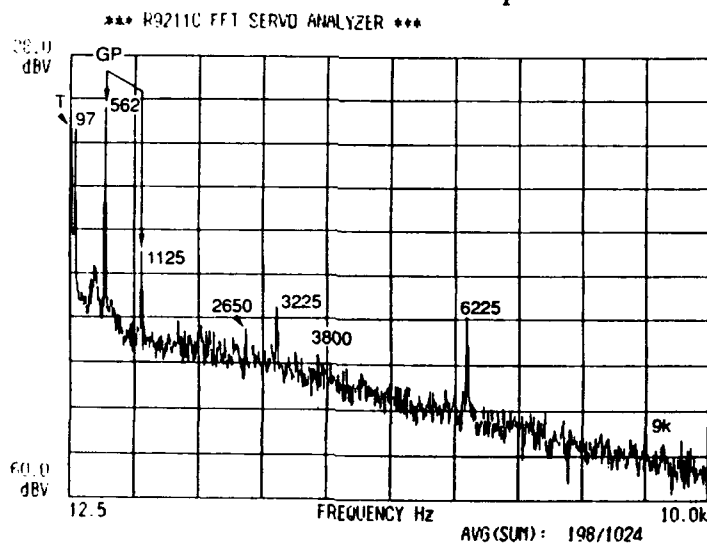

*** R9211C FFT SERVO ANALYZER ***

Figure 32:   180° at position D at 2400m. Over a span of 10 kHz many spikes in the higher frequency
region at the tail part are found. The 1GP spike (Gas Producer) at 562 Hz is the strongest,
also visible are 3T and 2GP. The other spikes at 3225 Hz, 3800 Hz, 6225 Hz and 9000 Hz
are also measured with the accelerometers, but they are of unknown source, i.e. not listed in
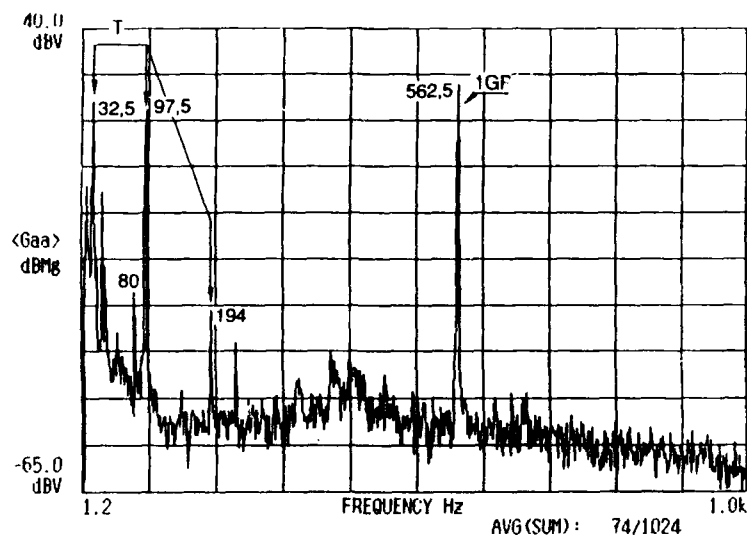the rotortuner sheet.

Figure 33:   Ditto as figure 32. Zoomed in to 0-1 kHz. More details are visible now, like the 1T, 3T, 6T
and 1GP spikes.

5.2.5   Helicopter at a distance of 4 km (position D) at 0° angle

With the naked eye the helicopter was scarcely visible, but the vibrations of it are still
measurable. Because of the 0° angle of the helicopter we only see relevant spikes in the lower part
of the spectrum (see next page). Here again the 1R, 3R, 1T, 3T, 1TRDS, 2TRDS and 1GP spikes
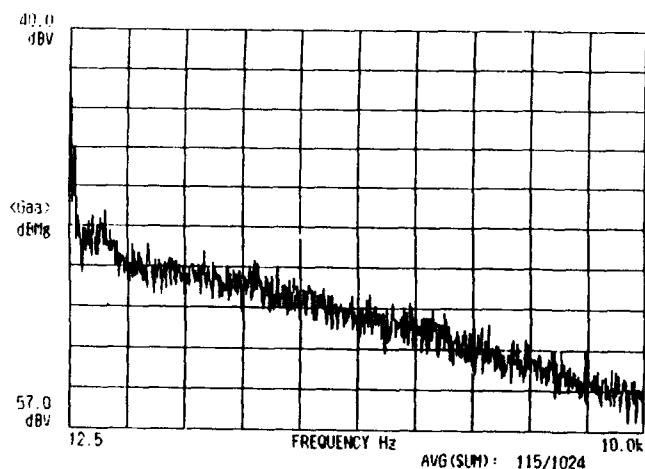show up. Because of the poorer Signal-to-Noise ratio, averaging is used.

Figure 34:   Position D at 4 km 0°.
Span 10 kHz. Averaged over
35 sec.

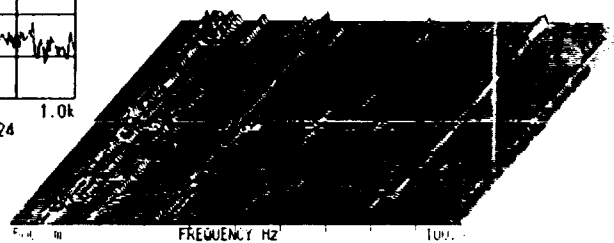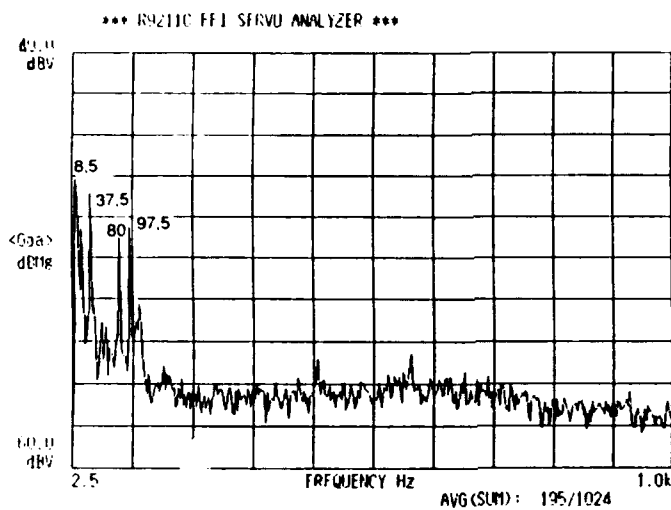Photo 8:   Alouette III at 4 km.

*** R9211C FFI SERVO ANALYZER ***

Figure 35:   Ditto as in figure 34. Span 1 kHz.   Figure 36:   3D waterfall over 20 s.

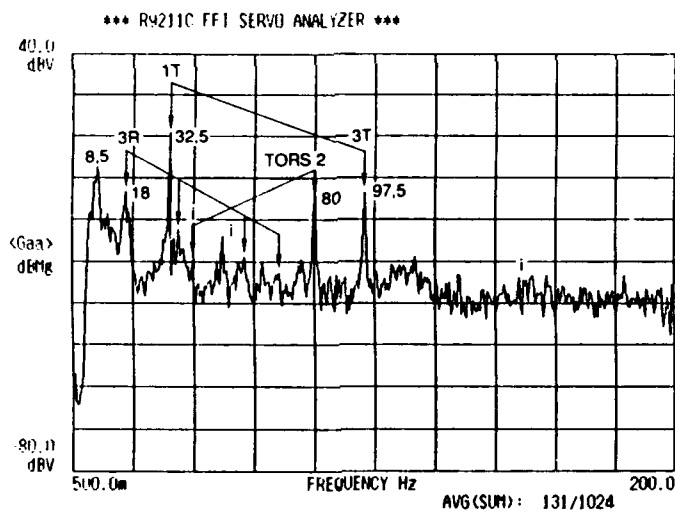*** R9211C FFI SERVO ANALYZER ***
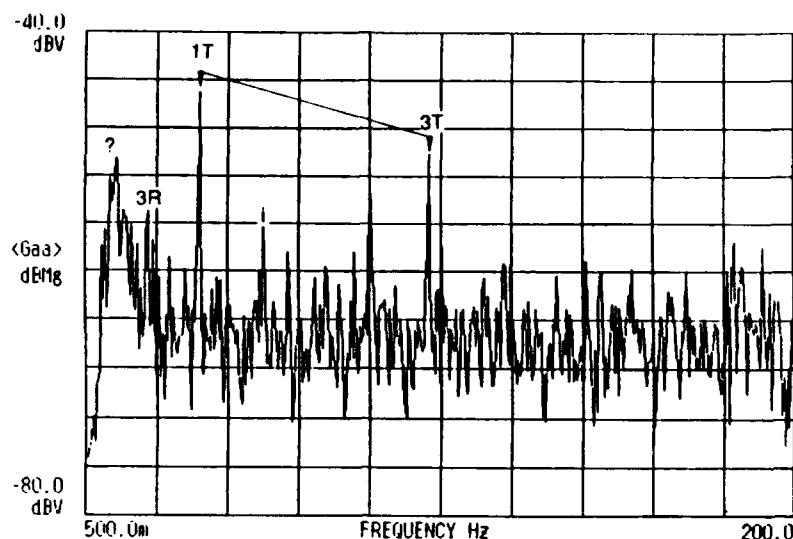

Figure 37:   Ditto as fig. 34. Span 200 Hz.

Figure 38:   Ditto as figure 37: Averaged over only 3 seconds. The graph is still acceptable and has
distinctive spikes.

5.2.6   Helicopter at a distance of 6 km

Because of an incorrect adjustment of the Video camera/ crosswire, the laser beam could not be
aimed quick and exact at the target. Sometimes, during scanning of the mirror, a signal was
received, but it was not sufficient in order to get the vibration data. Surely, in case of exact aiming
of the beam, it ought to be possible to obtain a useful signal.

5.2.7   Acoustic Measurements

During this helicopter experiment, another Group at TNO-FEL (the Radar & Communication
group, Special Applications dept.), did   acoustic/seismic measurements using an array of five
microphones/geophones mounted four meters apart.

Very good detectable were the 3R and 3T spikes with harmonics, due to the blade passing.
Earlier, this group carried out measurements at a number of helicopters.[4]

Currently, a classifier for helicopters is being studied.

The graph on the next page depicts the results of the acoustic analysis of this helicopter at a
distance of approx. 1 km. Wind effects in the microphones caused an increase of the noise level in
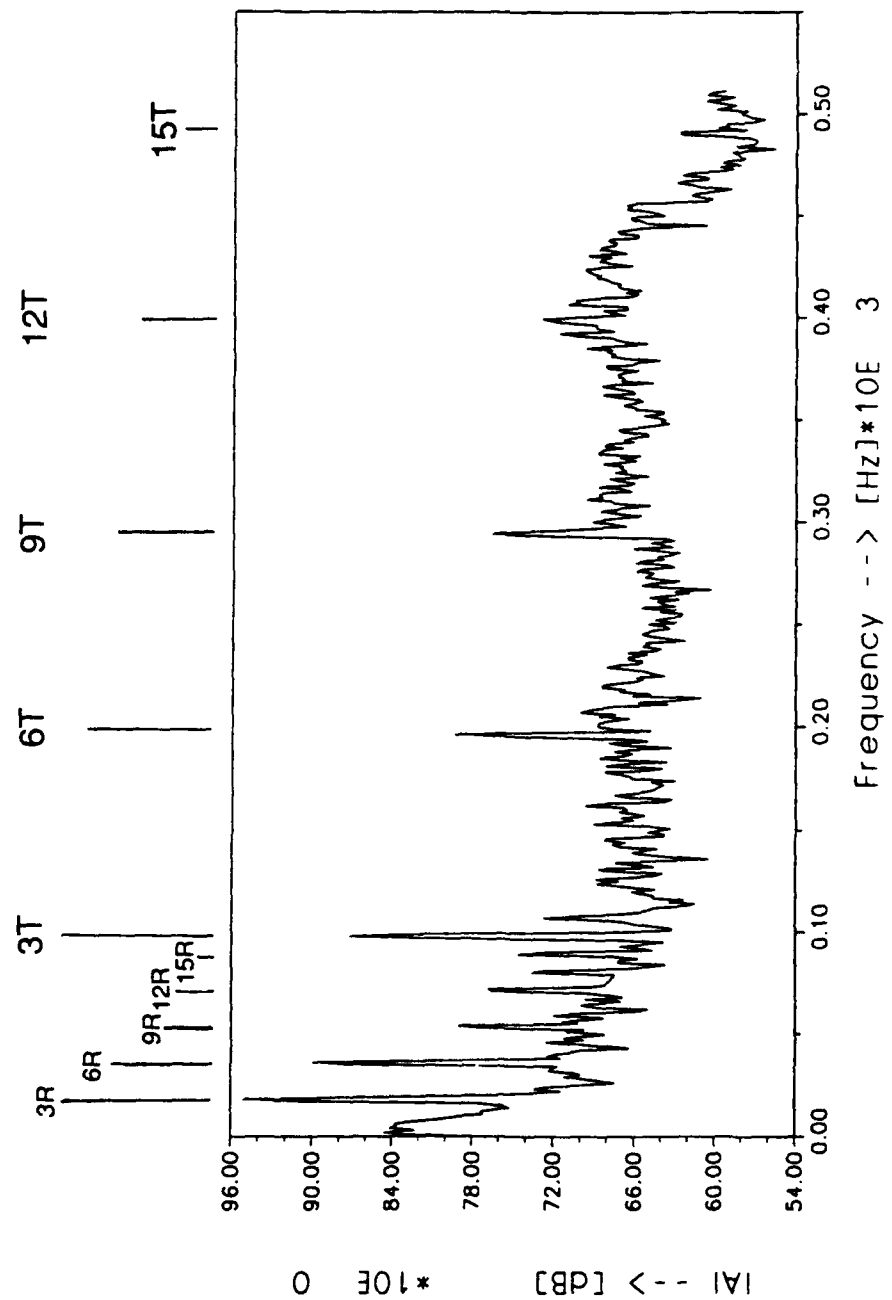the low frequency part.

Figure 39: Acoustic vibration detection at a distance of 1 km from the helicopter at position B, using an array of five microphones mounted four meters apart. (Courtesy A.C. van Koersel).

5.3   Testing measurements

The linearity of the system was tested before the trial was started.

An extra check concerning the effects of interference was done in the shed on the roof of the TNO-FEL building. The aim was to determine system vibrations, low-frequency interference signals of the heterodyne set-up. The measurements were carried out with the laser beam pointed at the asphalt of the parking lot at a distance of ≈100 meters and towers at distances up to 5 km.

5.3.1   Interference caused by the measurement system

Within the IF bandwidth of the FM receiver of 120 kHz, interferences were hardly visible, only some hum at 50 Hz and 150 Hz is detectable some 5-10 dB above the noise level.

The level of interference depends on ground loops and hum in the DC power supply and the HT supply of the laser stabilizer. Vibration interference spikes of the set-up, due to the cooling etc., became apparent within the audio spectrum only in the smaller IF bandwidths (12 and 7.5 kHz), which were not used during this trial.
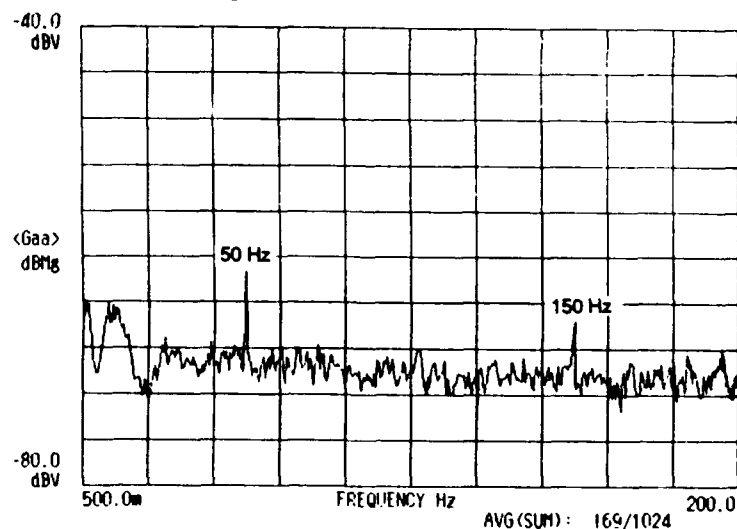
Figure 40:   Test; a church-tower at 3 km. Averaged over 40 seconds.

5.3.2   Interference caused by the laser stabilizer

Best measurement results are obtained with a laser stabilizer in HOLD position. The HOLD-function keeps the control voltage temporarily constant and disables the dither. The 512 Hz dither modulation is no longer present and the vlf noise 5-50 Hz coming from the regulating loop amplifier of the laser stabilizer, does not cause any interference effects anymore.

6   CONCLUSIONS AND RECOMMENDATIONS

Alouette III helicopter vibration data are obtained with a CO_2-laser system, emitting a beam of less than 0.5 Watt.

The vibrations of this target have been measured up to 4 km. The detected frequencies are in the range of 5-1100 Hz, depending on which side of the helicopter the laser beam is aimed at. The largest spikes are found in the 5-600 Hz range.

Typical frequency spikes of the main rotor (R), tail rotor (T), tail rotor drive shaft (TRDS) and gas producer (GP) etc. recurred in the spectra, at various angles and target ranges.

The R and T vibrations and their harmonics are always found in the spectra and so the T/R-ratio as well. In our case the ratio is 5.49. The accuracy depends on the number of FFT points. We used 200, 400 or 800 points. The T/R-ratio is fixed and unique for every helicopter type, while the rotor speeds are stabilized within about 0,6 percent.

Other spikes in the frequency spectrum could be useful as well. Therefore, it should be possible to recognize the helicopter type in a few seconds using a database, even when using a laser system with a small power output.

One has to take into account though, that the amplitudes of the spikes in the frequency spectrum will vary significantly when different parts of the target are irradiated, or due to imbalance of the rotor blades.

-    It is also possible to measure at moving targets (flight situation) with the help of a sophisticated automatic frequency control in the FM receiver. As a result of the target's speed, a Doppler frequency offset of the 140 MHz FM signal is introduced. Due to the target's variations of speed, the received signal could fall outside the detection bandwidth of the FM receiver, thus receiving nothing at all.
     A suitable and rapid AFC/autoscan system should be developed, e.g. using a "real-time" spectrum analyser in the AFC.

-    A video tracking system controlling the scan mirror of the set-up is necessary, when aiming at moving targets.

-    The small divergence and diameter of the laser beam has precise aiming possibilities. The laser system can also be used for vibrometric diagnostic of objects of any kind and measuring of movements at ranges of several kilometers.

-    In a new vibrometer, the power loss of the laser by the AOM in the transmitter path is not needed and could be moved to the LO-path, in order to get more output power.
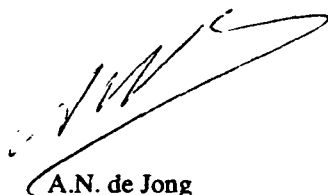
-    Recent developments in the semiconductor laser technology for shorter wavelengths clear
     the way for development of a new small and handy version of a heterodyne detection CW-
     laser system. Very interesting are the new diode-pumped single-mode Nd:YAG-, Erbium
     and Holmium lasers, because they have an acceptable low frequency jitter for this
     application.

     Other advantages are: the systems are very small, have a high efficiency, and liquid nitrogen
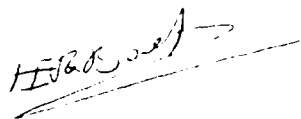   cooling for the detector is not required.

     The shorter wavelength makes it also possible to measure (or to make audible) very small
     vibrations with amplitudes near 10 μm or less.

BIBLIOGRAPHY

[1] Boetz ing. H.E.R., Vibration Measurements with a multifunctional CW CO_2-laser system during the BEST TWO trial, FEL-91_A104.

[2] Hebers ir. H., Set-up and alignment aspects of a CO_2-laser radar for applications in the field, FEL-91-A162.

[3] Henstra dr. A, Laser vibrometry of moving targets, FEL-92-B252.

[4] Hoof van ir. H.A., Bol A.I., Collection of helicopter signatures with mechanical wave sensors, phase 2, FEL-90-A156

[5] Lerou drs. R.J.L., Bentvelsen ir. P.H.C., Opbouw en werking van een multifunctie CO_2-laserradarsysteem, FEL-91-A161.

[6] Timmerman AOO. J.H., KTO Helitune, Koninklijke Luchtmacht te Soesterberg, KTO 1991.

[7] Vreede drs. J.P.M. de, Heterodyne detectie van laserstraling, PHL 1978-18.
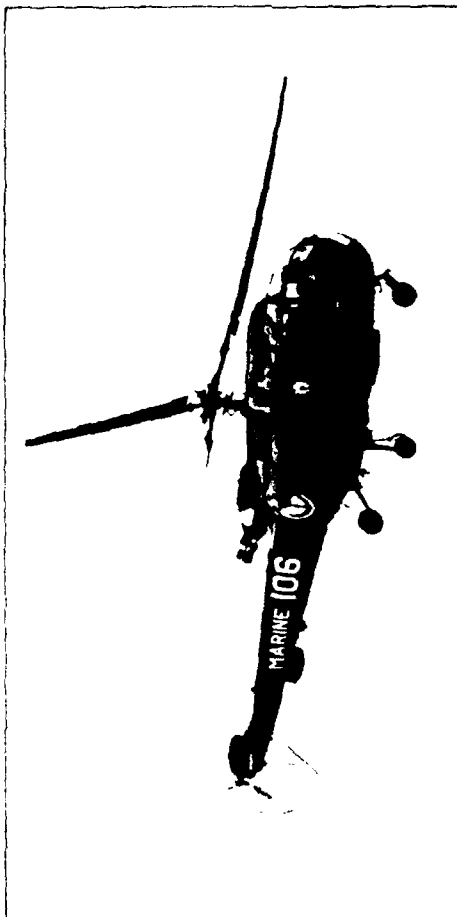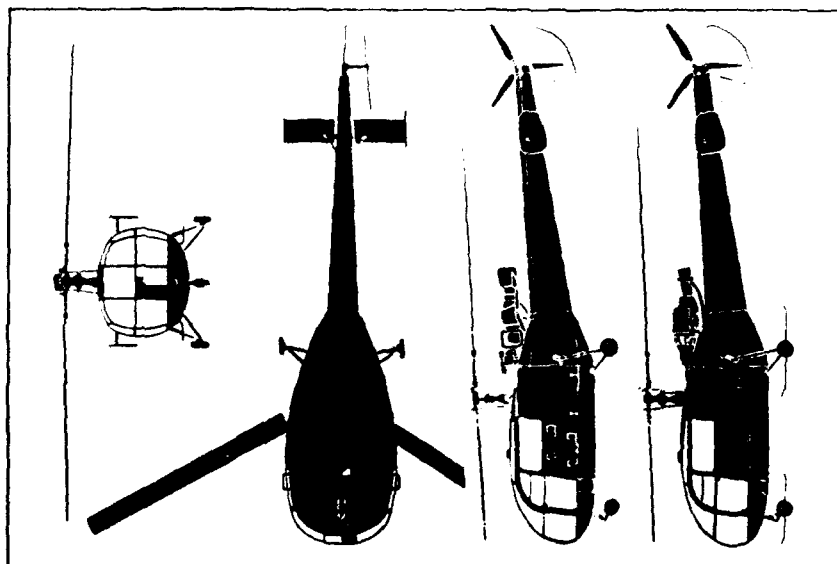
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Aérospatiale Alouette III

Contusion Alouette II, Gazelle

Power: 1 × Artouste or 1 × Astazou turboshaft

Rotor dia: 36ft 1¾in (11.02m)   *Length* 32ft 10¾in (10.03m)

The Alouette III series was derived from the Alouette II, offering a larger cabin, more powerful engine and improved performance. The type first flew in 1959 as the SE.3160, and later production aircraft were designated SA.316B. Some 1,450 Alouette IIIs of all versions had been delivered to a number of operators in more than 70 countries by early 1964. The SA.316B has also been built under licence in India as the Chetak, and in both Switzerland and Romania. The SA.319B, a direct development of the SA.316B, is powered by a 870shp Turboméca Astazou engine. First flown in 1967, the type is still in production in Romania. Powered by an 870shp Turboméca Artouste turboshaft, the SA 316B cruises at 115 mph (185km/hr) while the SA 319B cruises at about 120 mph (190km/hr)   *Country of origin* France *Main silhouette* SA 316B *lower sideview* SA 319B

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REMOTE VIBRATION MEASUREMENTS AT A SUD AVIATION ALOUETTE III HELICOPTER WITH A CW CO_2-LASER SYSTEM

11. AUTHOR(S)

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15. ABSTRACT (MAXIMUM 200 WORDS, 1044 POSITIONS)

THIS REPORT DESCRIBES AN EXPERIMENT WITH A HELICOPTER TO QUANTIFY THE PERFORMANCE OF OUR EXPERIMENTAL MULTIFUNCTIONAL CO_2 LASER HETERODYNE DETECTION SYSTEM[5,7] AS A VIBRATION DETECTION INSTRUMENT. THE LASER SYSTEM EMITTED A BEAM WITH A DIAMETER OF 35 MM WITH A DIVERGENCE OF 0.5 MRAD AND A CONTINUOUS OUTPUT OF 0.4 WATT.

THE PURPOSE OF OUR MEASUREMENTS WAS TO MEASURE THE VIBRATION SPECTRA OF A HELICOPTER FROM THE DUTCH AIR FORCE AT DISTANCES BETWEEN 0.5 TO 6 KM AT VARIOUS ASPECT ANGLES. VIBRATION DETECTION WITH THE HELP OF LASERS MIGHT PROVE IMPORTANT FOR CLASSIFICATION OF TARGETS. ESPECIALLY HELICOPTERS ARE OF INTEREST BECAUSE OF THE TYPICAL CONSTANT ROTOR SPEEDS AND FIXED SPEED-RATIO'S BETWEEN THE TAIL- AND MAIN ROTOR (T/R-RATIO) AND OTHER CHARACTERISTICS OF THE SPECTRA.

THE OBTAINED SPECTRAL COMPONENTS ARE COMPARED WITH MAINTENANCE (ROTORTUNING) FREQUENCY MEASUREMENTS DONE AT THE AIRBASE WITH ACCELEROMETERS. THE RESULTS ARE IN ACCORDANCE WITH EACH OTHER. THE ROTOR FREQUENCIES HAVE BEEN DETERMINED AT ALL POSITIONS OF THE HELICOPTER. DEPENDING OF THE PLACE WHERE THE LASER BEAM HITS THE TARGET, THE AMPLITUDES OF THE SPIKES IN THE FREQUENCY SPECTRUM MAY VARY SIGNIFICANTLY. WITH AN ADVANTEST R9211C FFT SPECTRUM ANALYSER A MEASUREMENT WILL TAKE AT LEAST ONE SECOND, YIELDING A FAIR RECOGNISABLE SPECTRUM AT DISTANCES OF THE HELICOPTER UP TO 4 KM.

16. DESCRIPTORS	IDENTIFIERS
CO_2 LASERS LASER APPLICATIONS TARGET ACQUISITION VEHICLE VIBRATION	DISTANCE MEASURING EQUIPMENT HELICOPTERS FREQUENCY MEASUREMENT

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